The Role of Space-based Measurements in Assessing Black Carbon Effects on Climate

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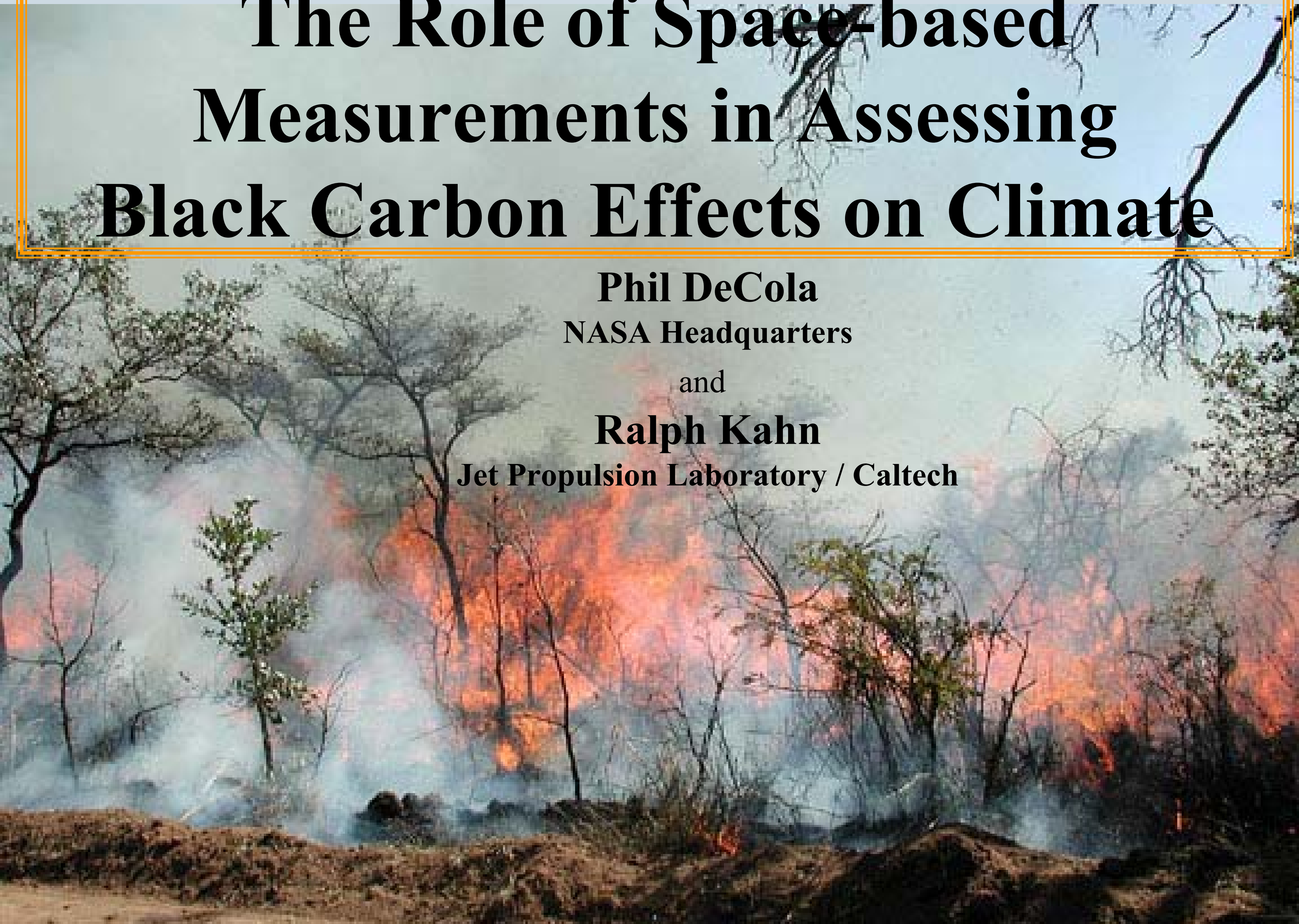
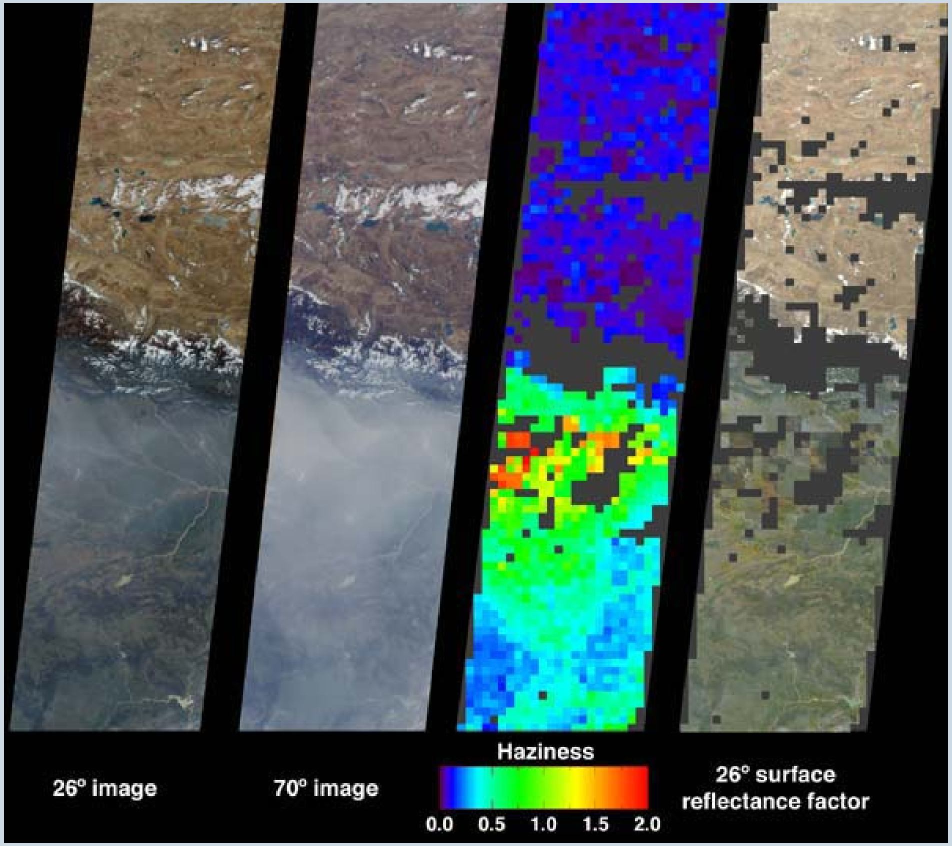


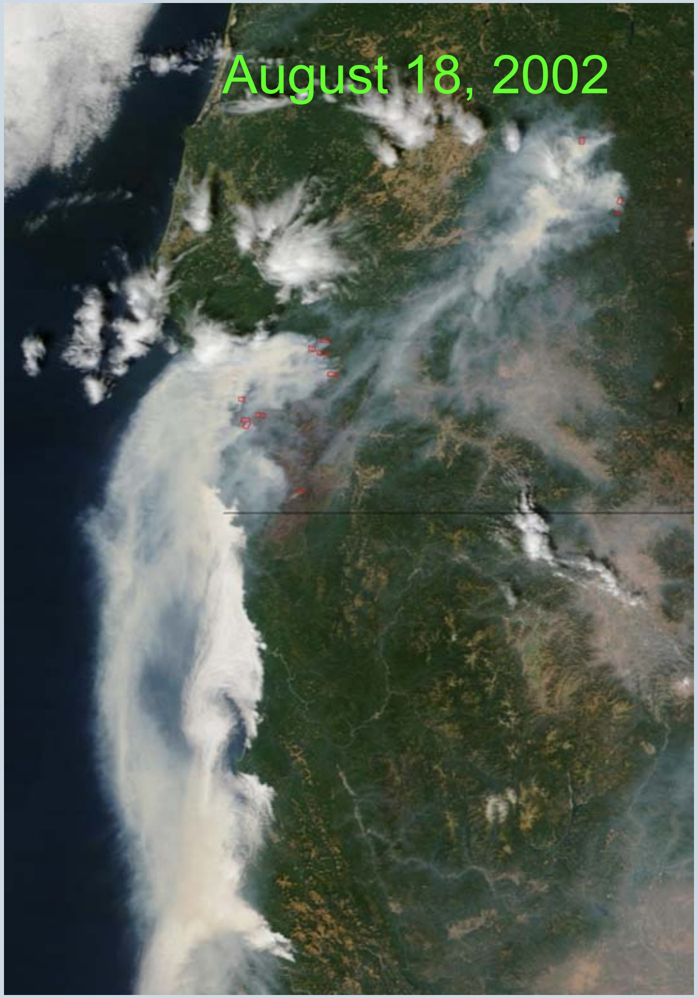
Science context:

A Regional Problem on a *Global* scale…

- Biomass Burning
- Urban and Industrial Pollution



Ganges Valley Pollution, India, Oct. 2001, observed by MISR



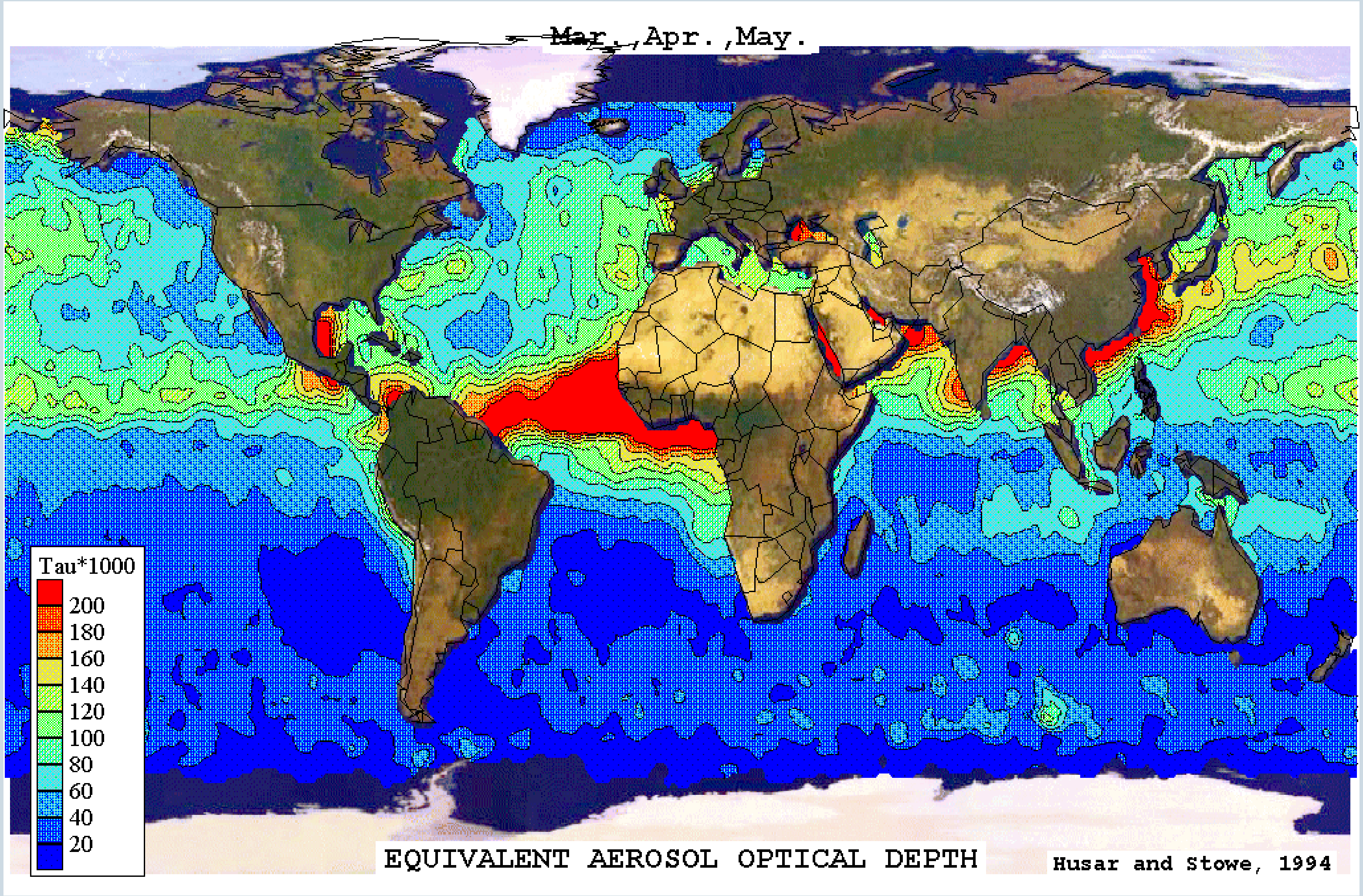
Biscuit Fire, Oregon, 2002, observed by MODIS

What can satellites contribute now?

- **Occurrence** -- number & distribution of fires (**MODIS** 4 times/day), and of fire & pollution aerosol plumes (**MODIS**; **MISR**; **GOES**; **SeaWiFS**)
- **Amount** -- Aerosol Optical Depth (AOD) and Aerosol Type, over land & water (**MISR**, **MODIS**)
- **Vertical Distribution** of smoke and pollution (LIDAR: **LITE, GLAS;** CALIPSO)
- **Plume Height** -- especially near source regions (**MISR**)
- **Single Scattering Albedo** (SSA) -- aerosol sunlight absorption (**OMI/TOMS** in UV; possible use of sun glint in visible; other ideas**)**
- **SSA** -- From coincident sunphotometer extinction AOD, adjust aerosol SSA so satellite scattering AOD matches (**AERONET** + **MODIS**; **MISR**)
- **Aerosol Source Location, Strength, Timing** -- satellite AOD distribution applied to back-trajectory or inverse aerosol transport model (**Inverse Model** + **MODIS**; **MISR; TOMS/OMI**)

What can we do from satellites? **Occurrence**

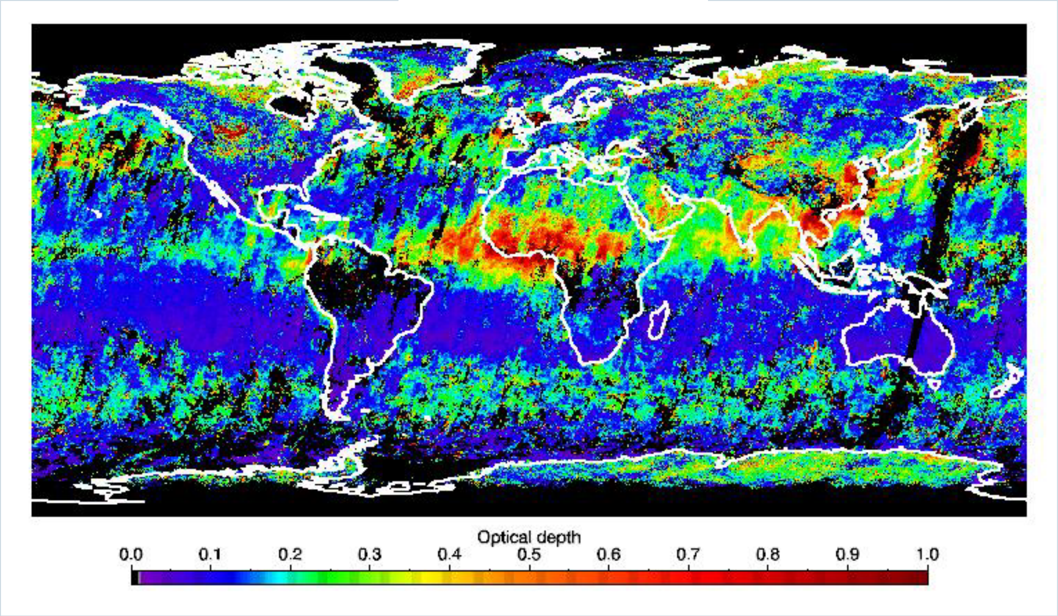
AVHRR 1-Channel Global Aerosol Optical Depth



Aerosol Type inferred from Location, Season, and Modeled Back-Trajectories

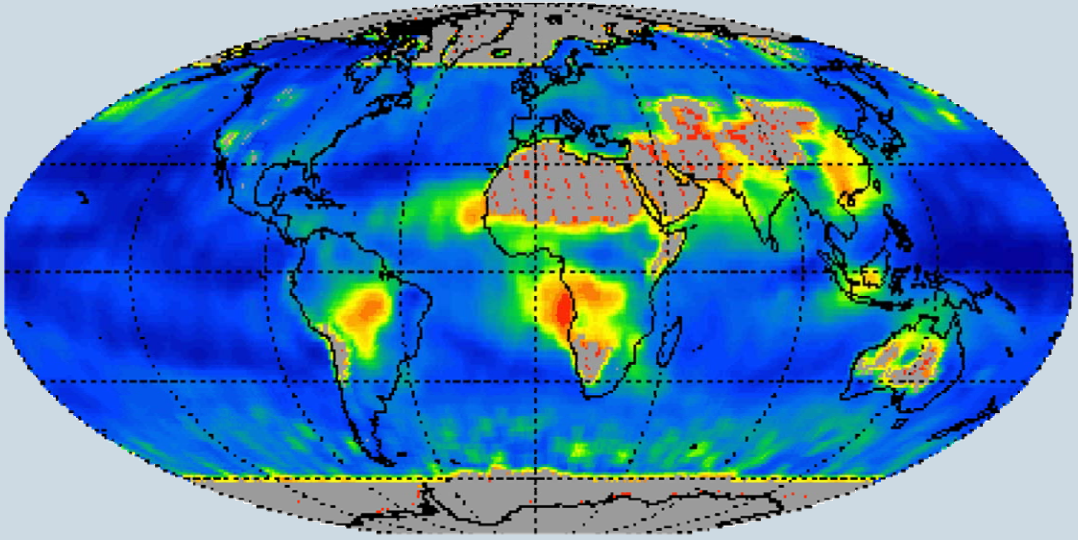
What can we do from satellites? **Occurrence**

Monthly Global Aerosol Optical Depth Products



MISR Mid-vis AOD
- Land & Water
- Bright Surfaces
- Globe ~ weekly
- ~ 10:30 AM

[+ particle size & shape]

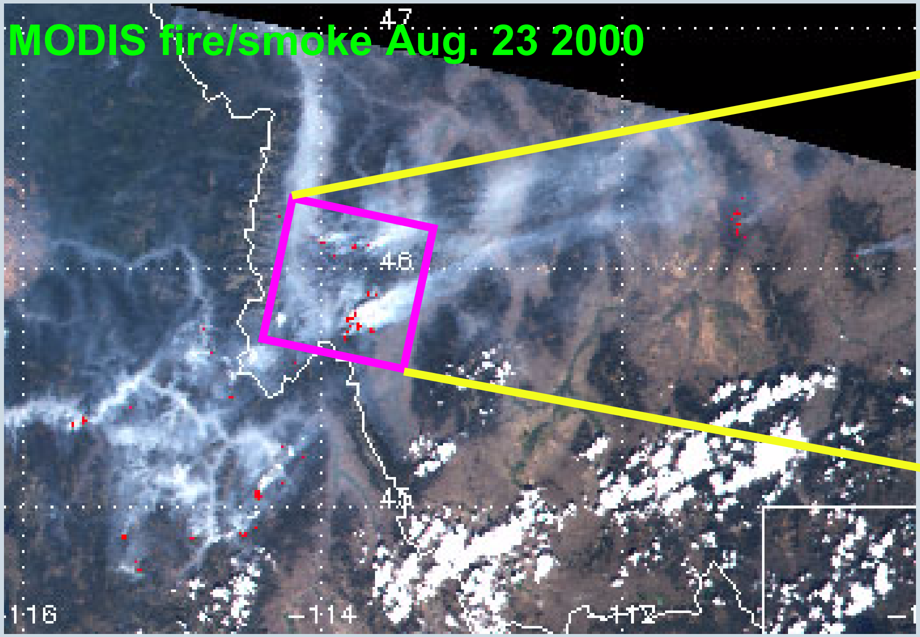


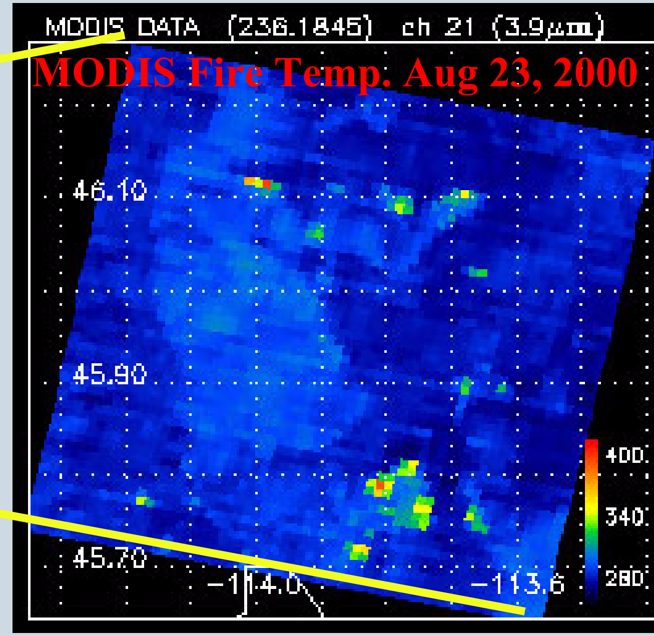
MODIS Mid-vis AOD
- Water & some Land
- Globe ~ every 2 days
- ~ 10:30 AM & 1:30 PM

[+ fine/coarse mode ratio]

What can we do from satellites? **Amount**

- **Number, Distribution and Apparent Strength of fires**



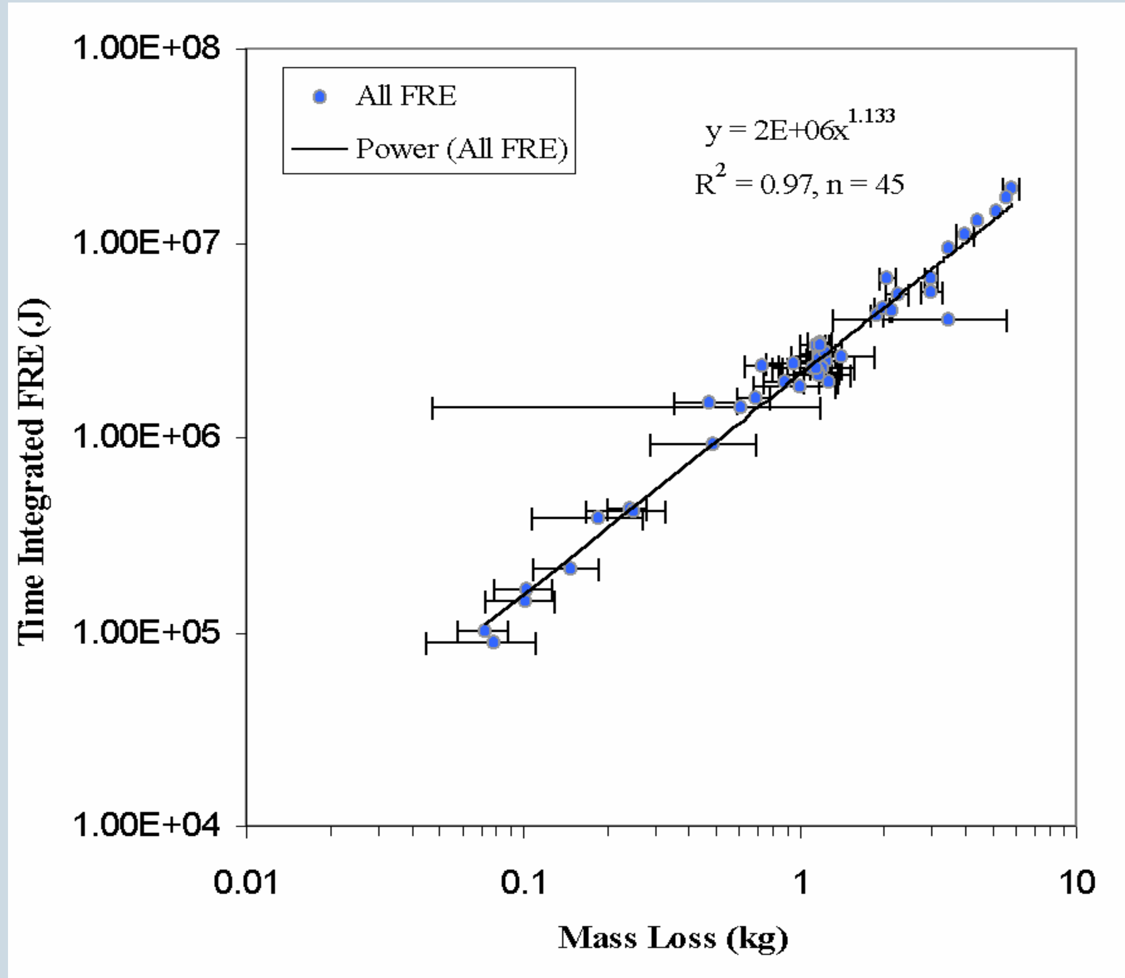


MODIS observes **Fire Brightness Temperature**, even through smoke --> fire radiative energy --> rate of biomass consumption

Measurements at 10:30 am/pm and 1:30 am/pm ±40 min. local time

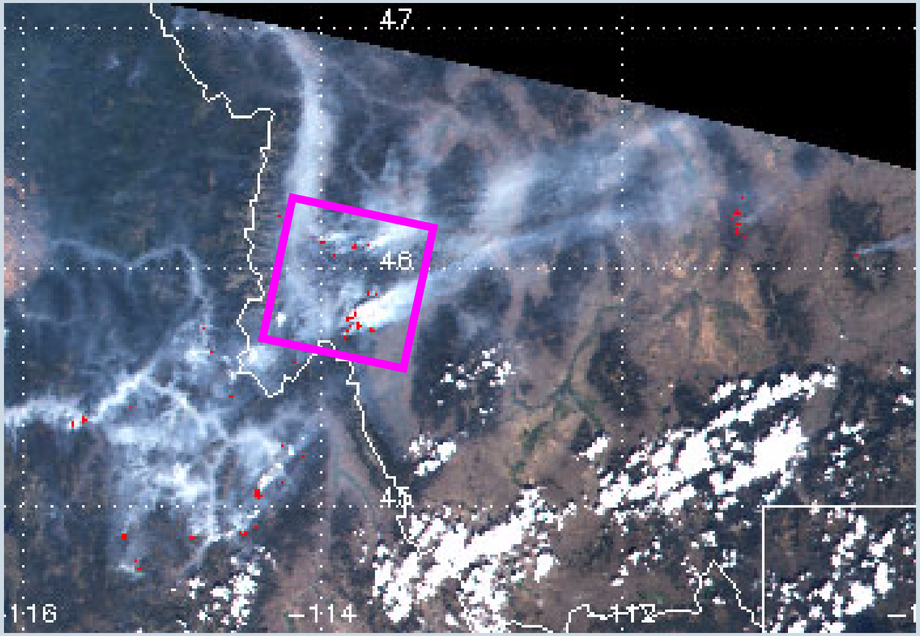
Correlation between Fire Radiative Energy (FRE) and Biomass Mass Loss From field measurements (Martin Wooster, Univ. London, UK)

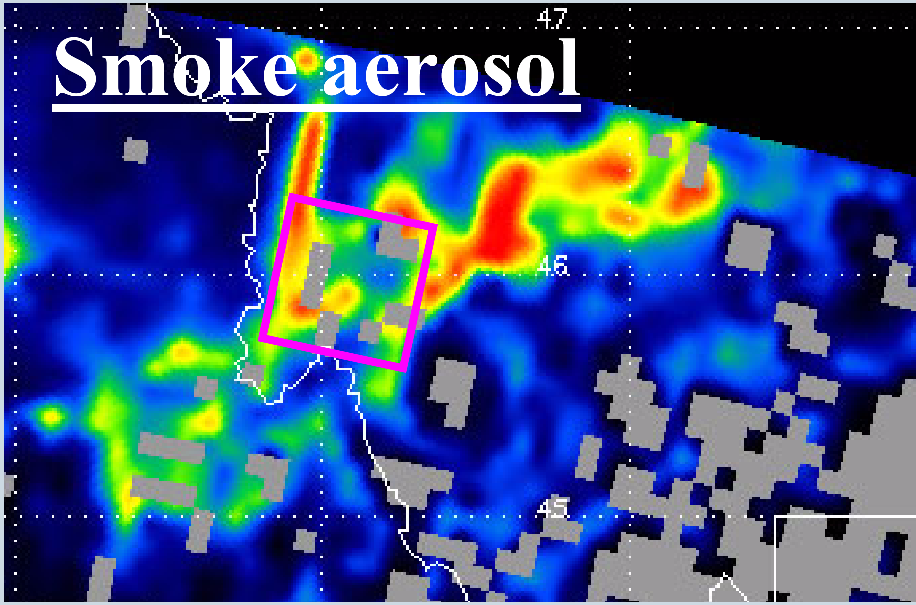
<u>Next Step</u>:
Stratify by Fire Type



Fire Temperature --> Radiative Energy, which relates to **Biomass Consumption** and **Aerosol Emission Rates**

MODIS also measures Amount of Smoke Aerosol (AOD) per Fire

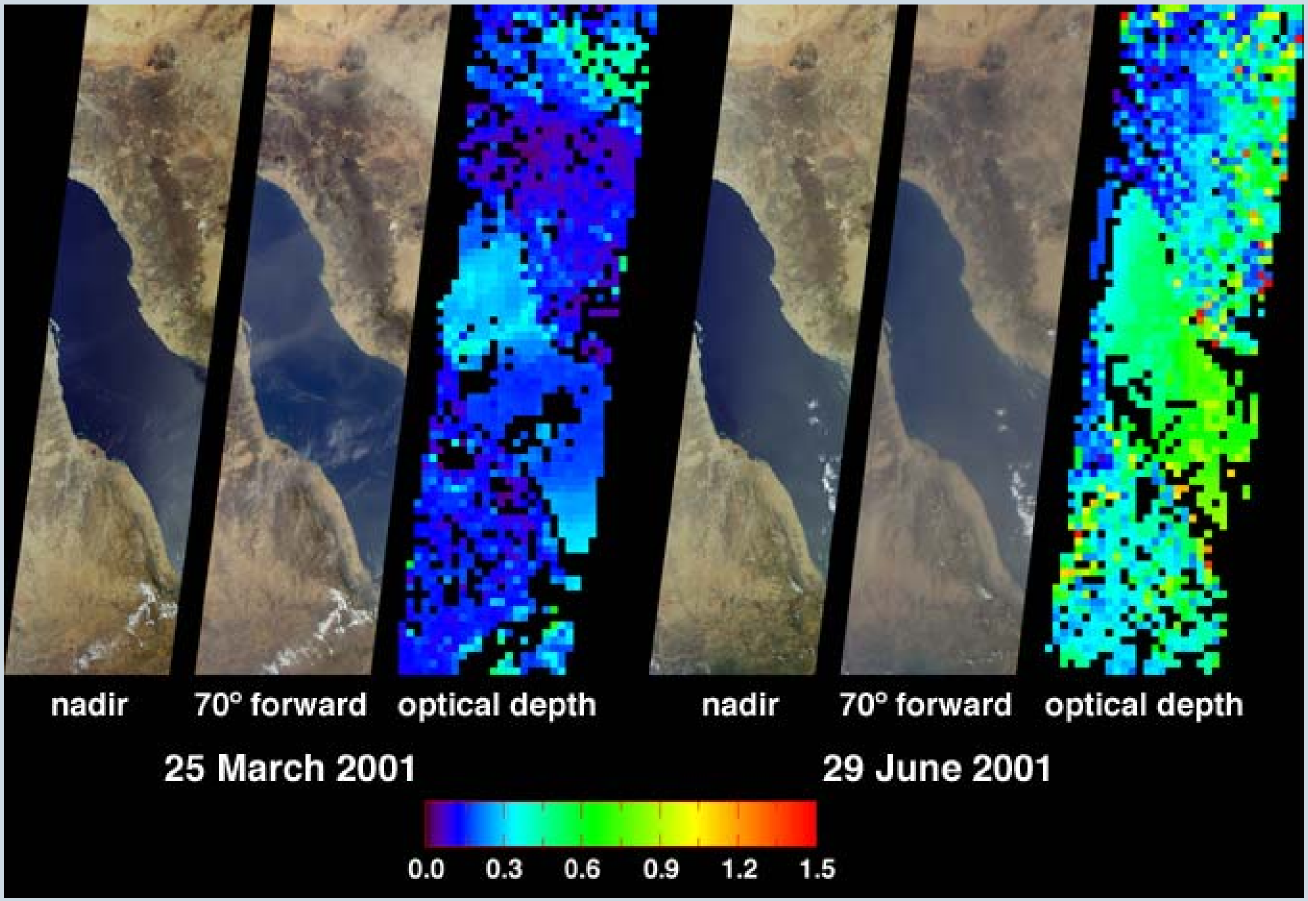




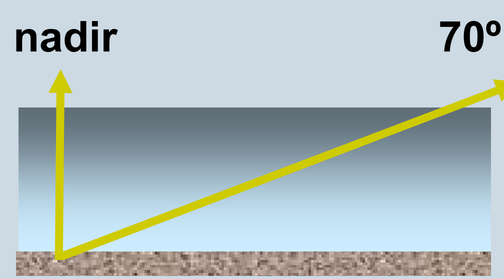
Can relate Fire Intensity measurements directly to Aerosol Amount measurements

What can we do from satellites? Amount

AOD over bright & dark surfaces (MISR)



Thin haze over land is difficult to detect in the nadir view due to the brightness of the land surface



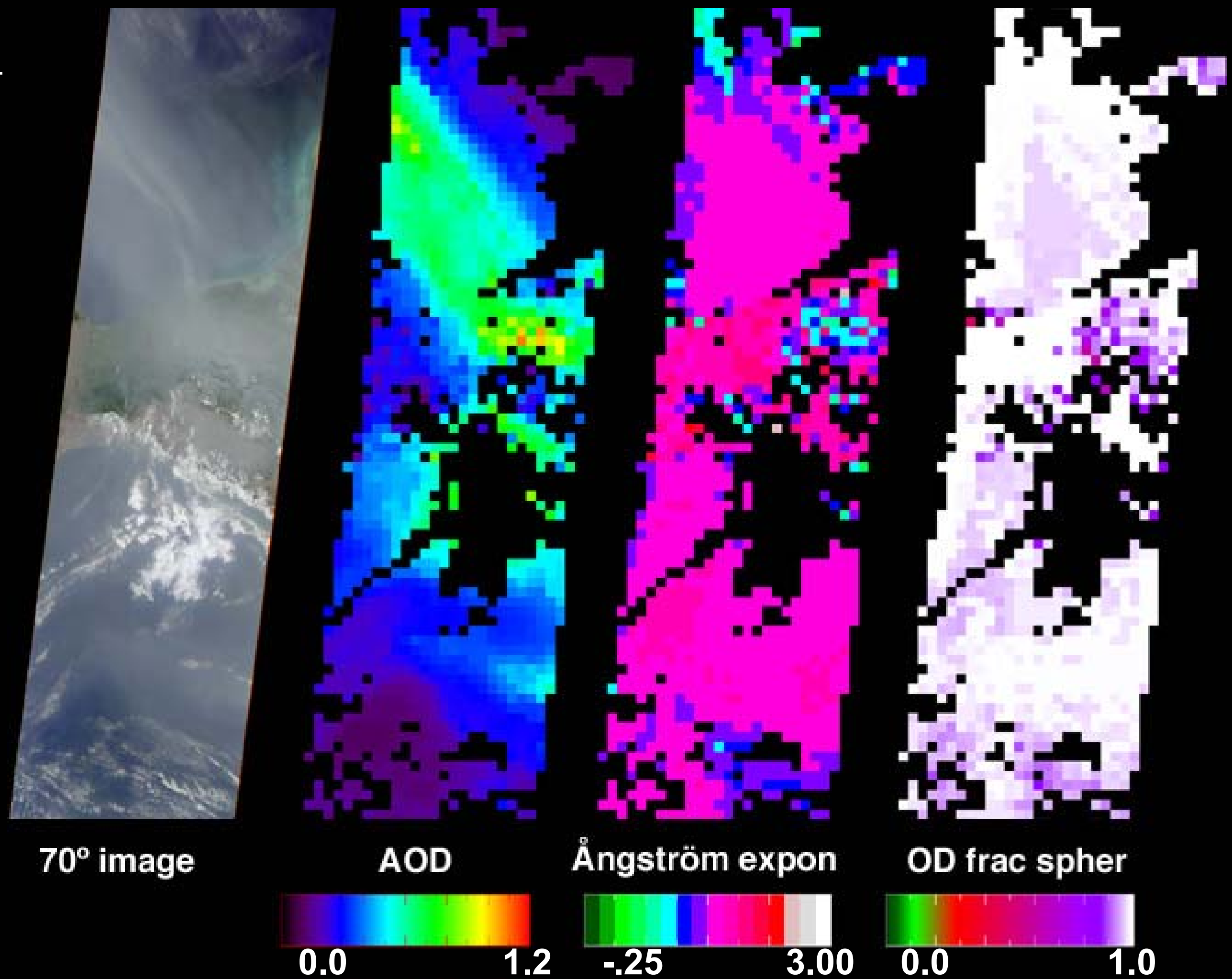
Saudi Arabia, Red Sea, Eritrea

Over Bright Desert Sites, mid-vis. AOT to ±0.07 [Martonchik et al., GRL 2004]

Smoke from Mexico (MISR)

2 May 2002

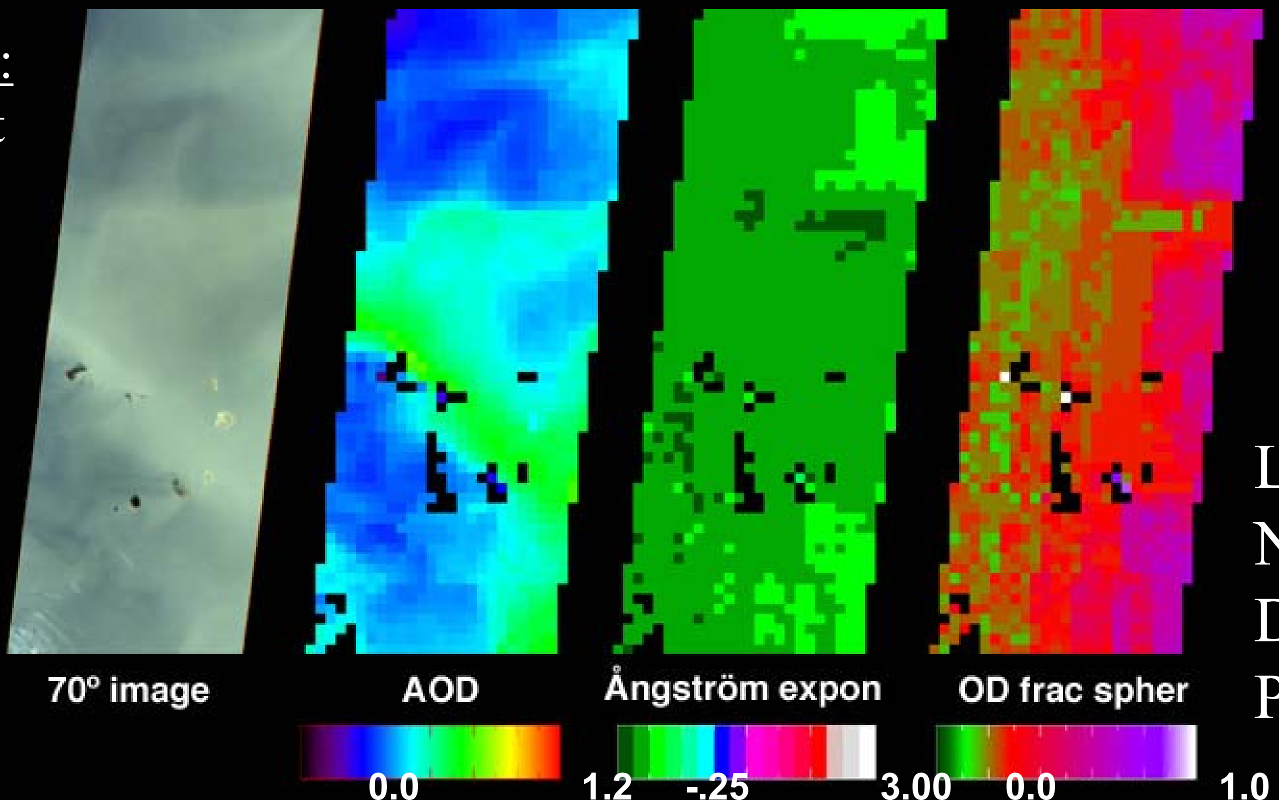
<u>Aerosol:</u>
Amount
Size
Shape



Medium
Spherical
Smoke
Particles

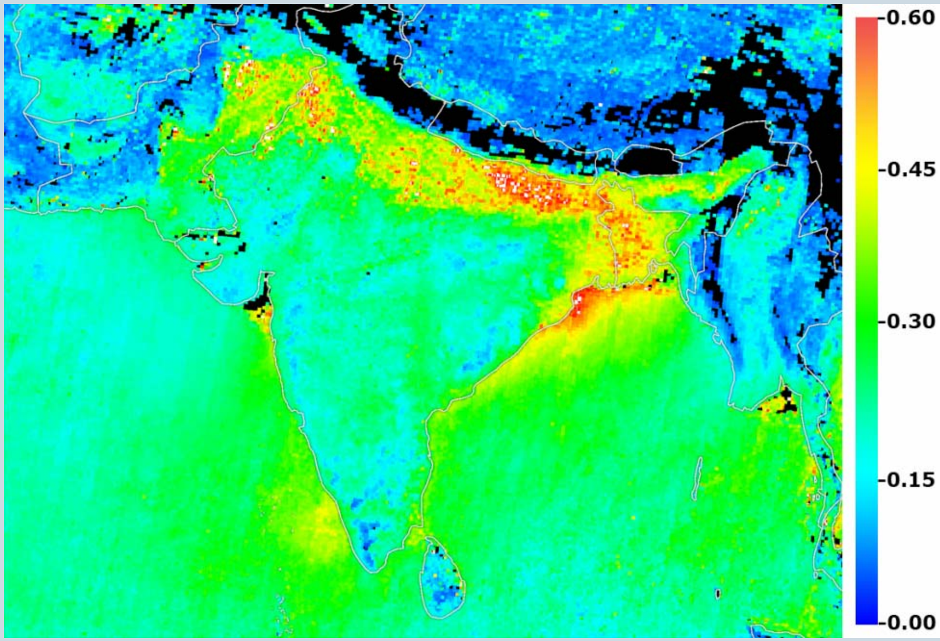
Dust blowing off the Sahara Desert (MISR)
6 February 2004

Aerosol:
Amount
Size
Shape

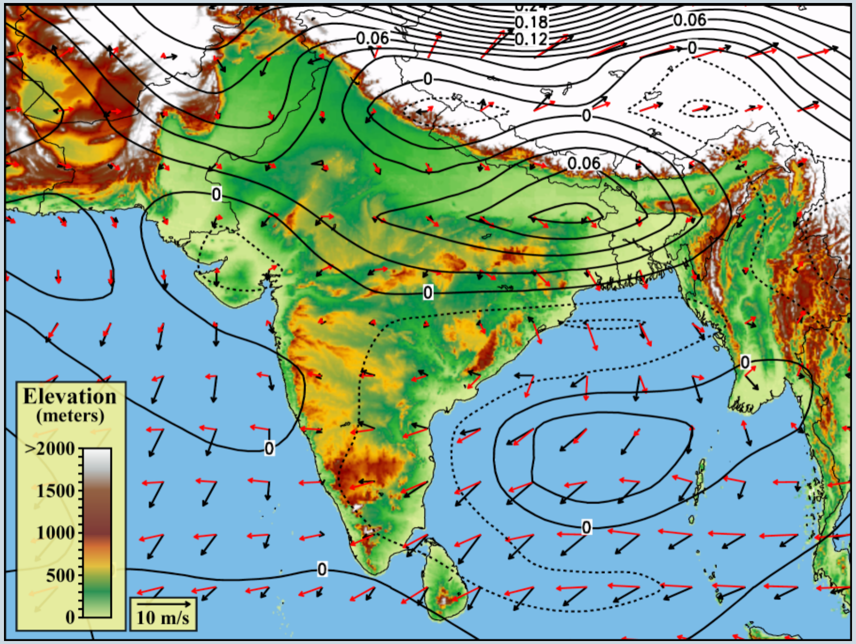


Large
Non-Spherical
Dust
Particles

Pollution Aerosol Concentrated in Ganges Valley near Kanpur, India (MISR)



MISR mid-visible AOD
[Winter, 2001-2004; white --> AOD >0.6]

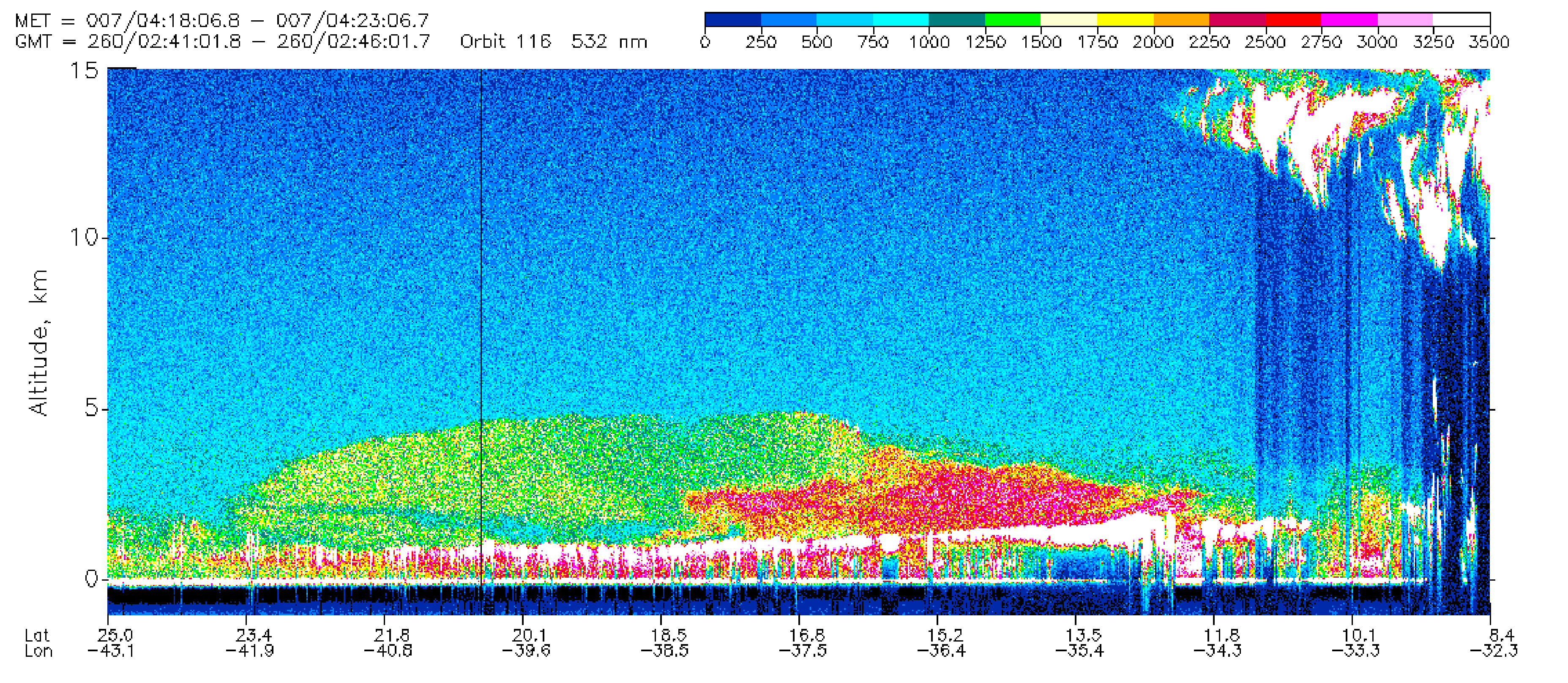


NCEP Winds + Topography
[Black=surface; Red=850 mb; contours=vertical, solid=subsidence]

L. DiGirolamo et al., GRL, 2004, submitted

What can we do from satellites? Vertical Distribution

LITE Shuttle-Based LIDAR
Saharan Dust over BL Aerosols + ITCZ



Orbit 116, Sept. 17, 1994

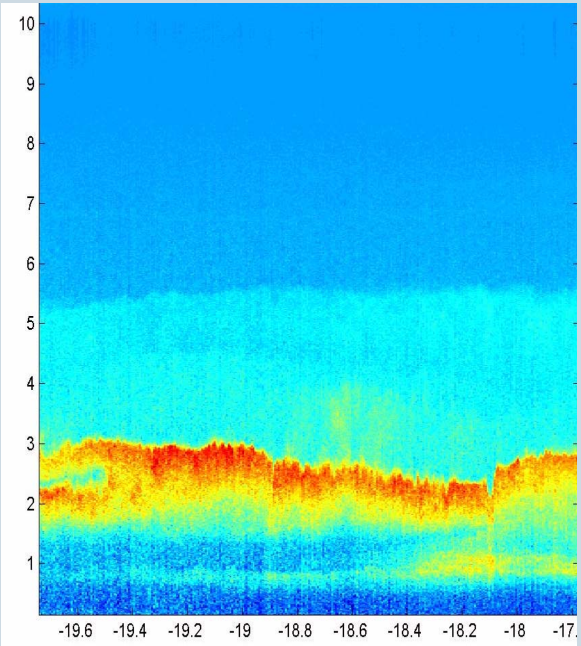
From -- LITE Web Site: http://www-lite.larc.nasa.gov

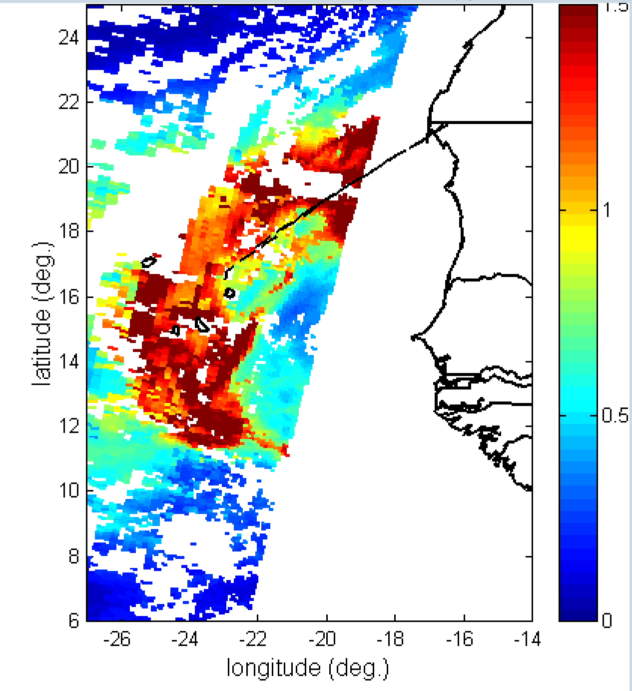
CALIPSO Launch scheduled for Spring 2005

Vertical Distribution of Aerosol + Column-ave. Fine/Coarse Size Ratio

Example◘ : Shade experiment - dust

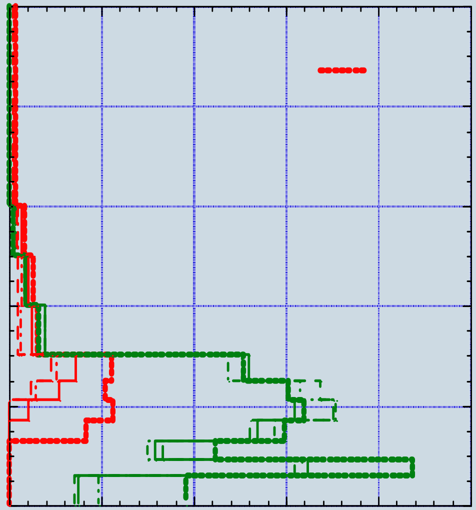
Lidar + MODIS INVERSION

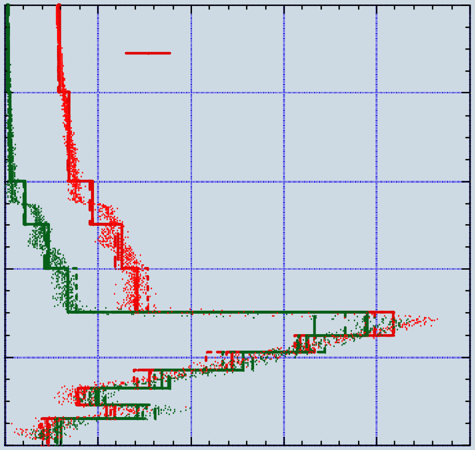


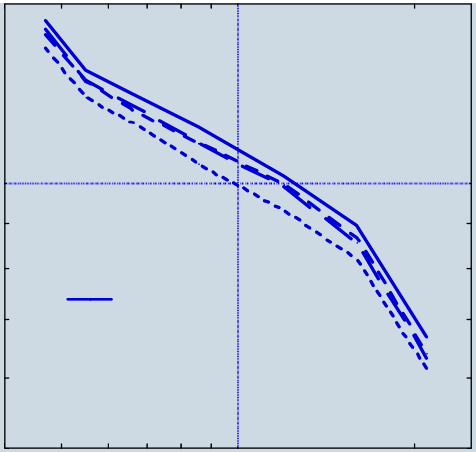


τ=0.85

τ_{fine}/τ=0.12





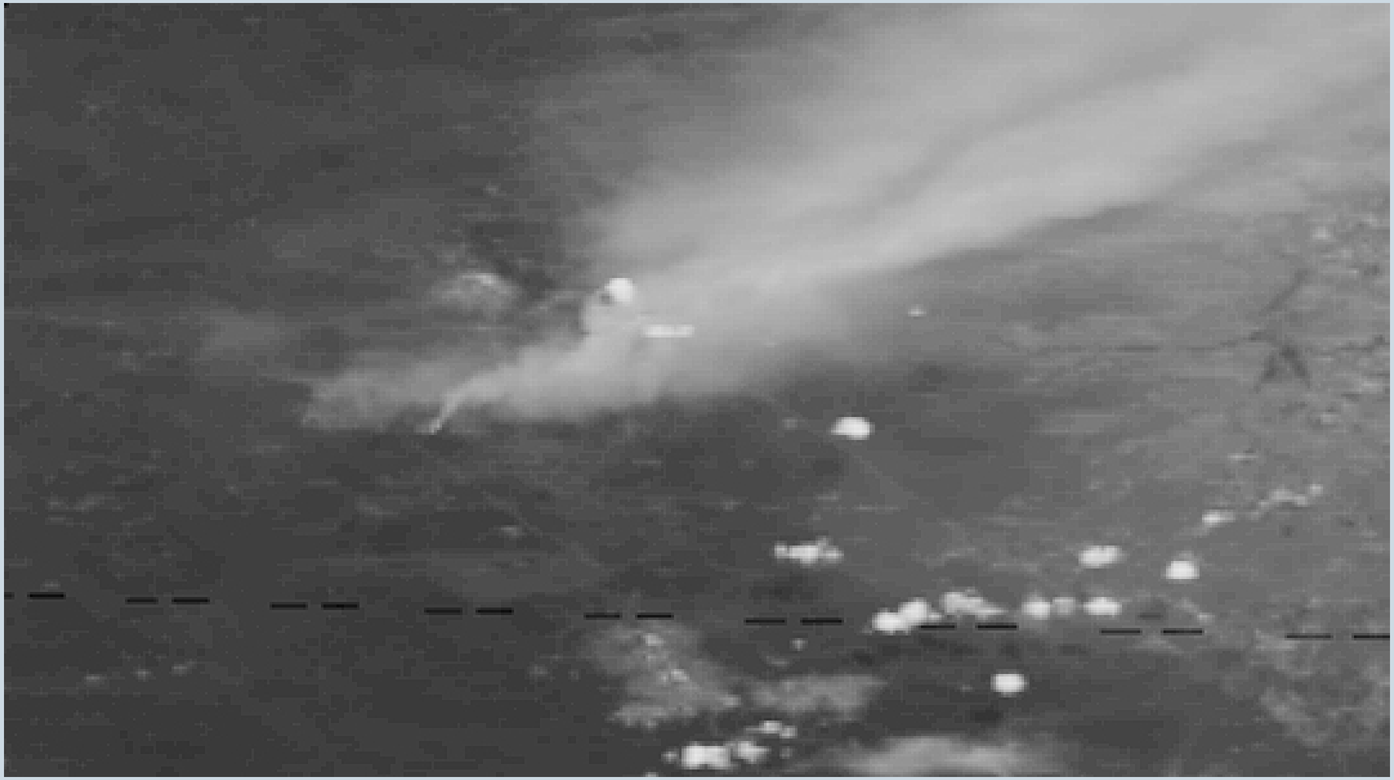


Application: A-Train

Kaufman et al., GRL, 2003

What can we do from satellites? **Plume Height**

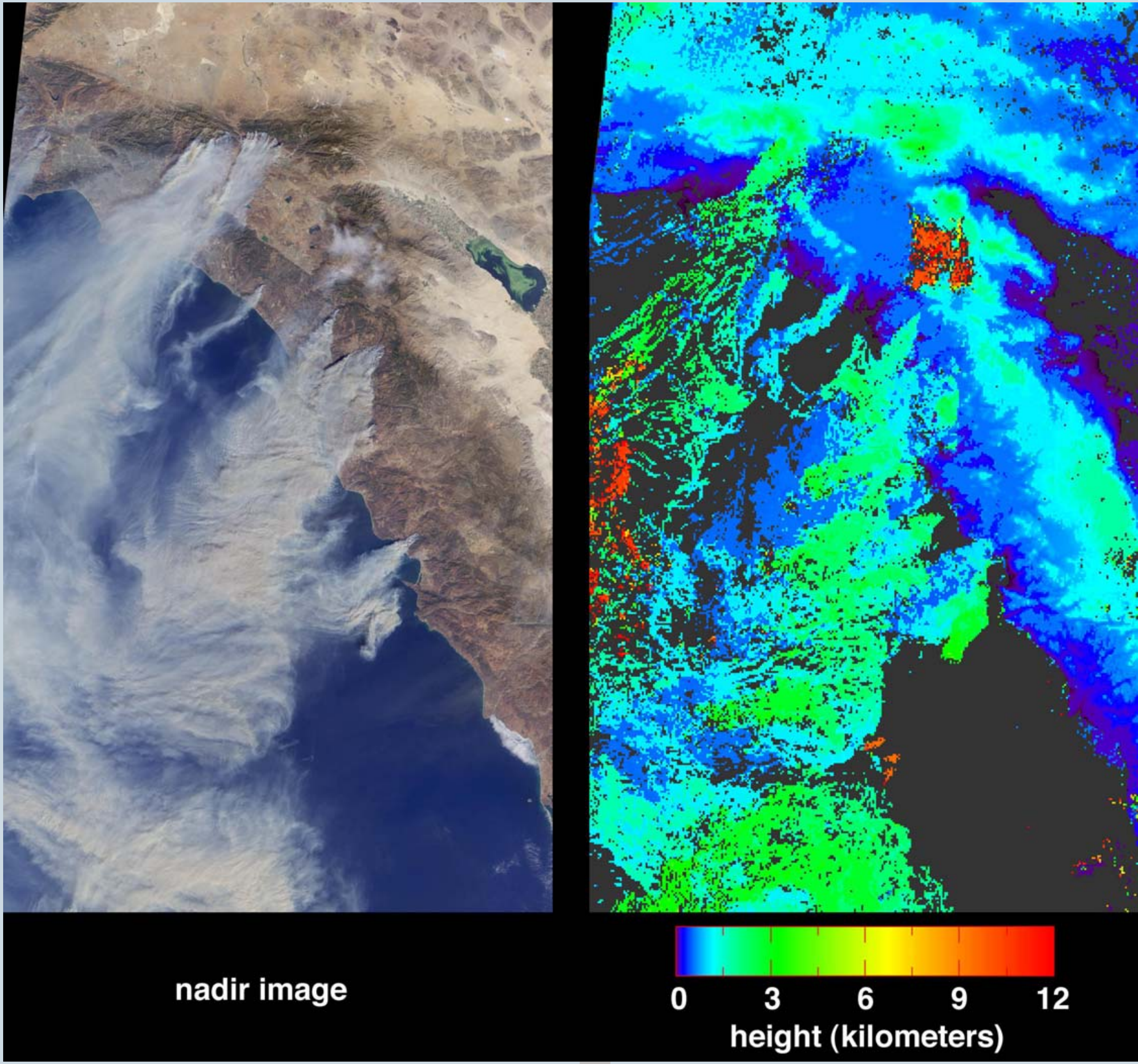
MISR Perspective views from 5 angles



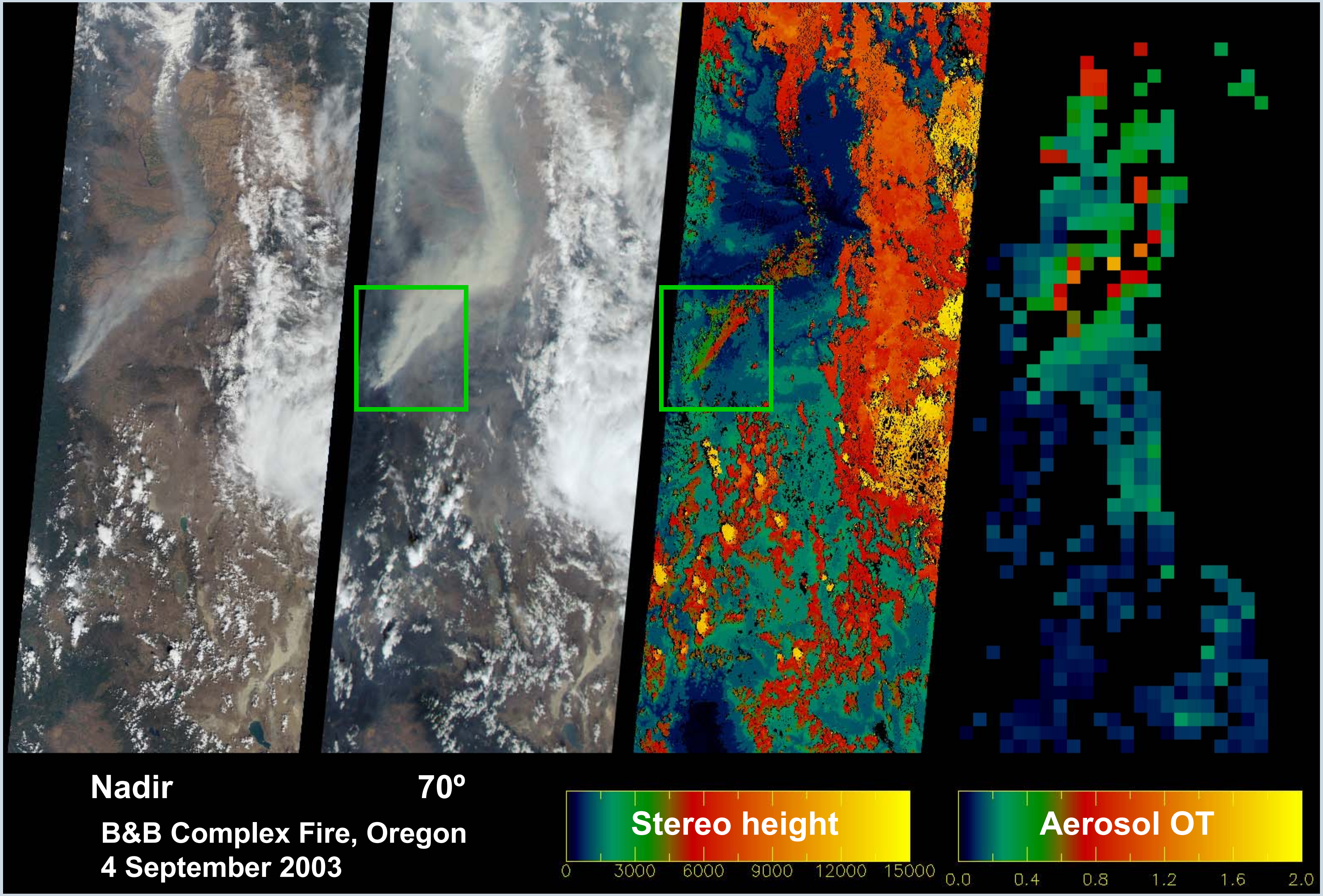
B&B Complex Fire, Oregon
4 September 2003

Los Angeles Fires
October 26, 2003

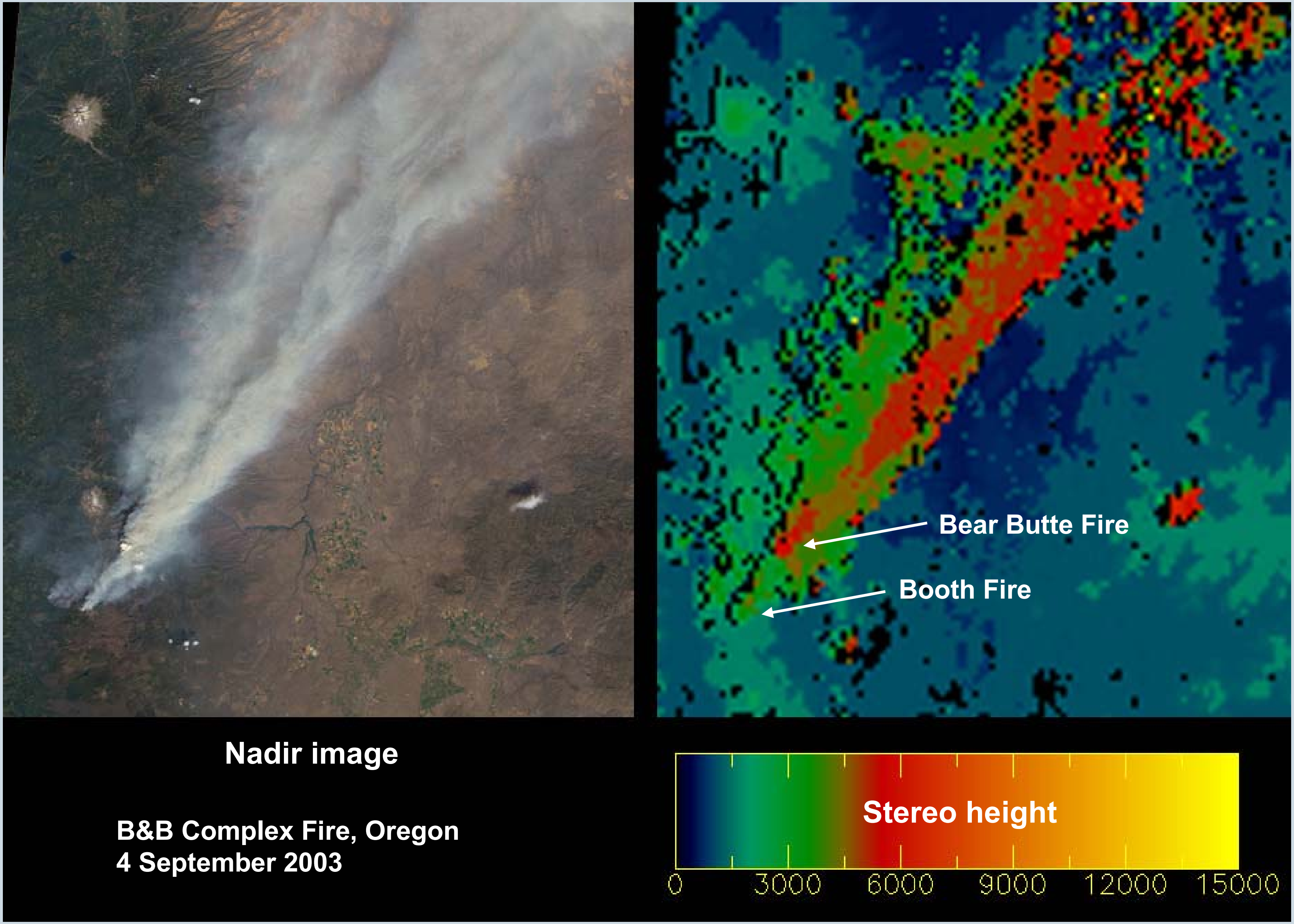
Fire Aerosol Plume Height (MISR)



Fire Aerosol Plume Height & AOD Observations (MISR)

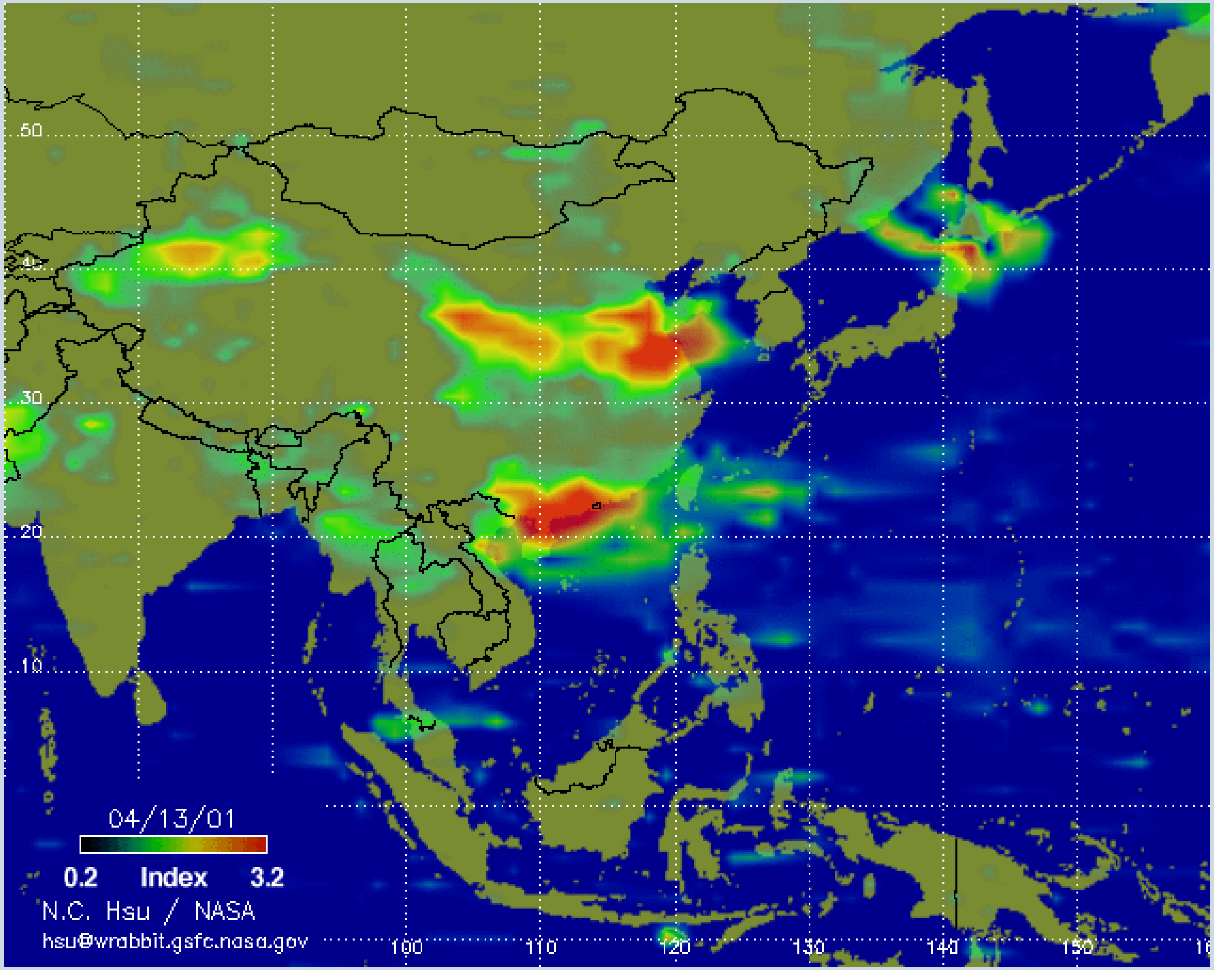


MISR Plume-height mapping using stereo (detail)



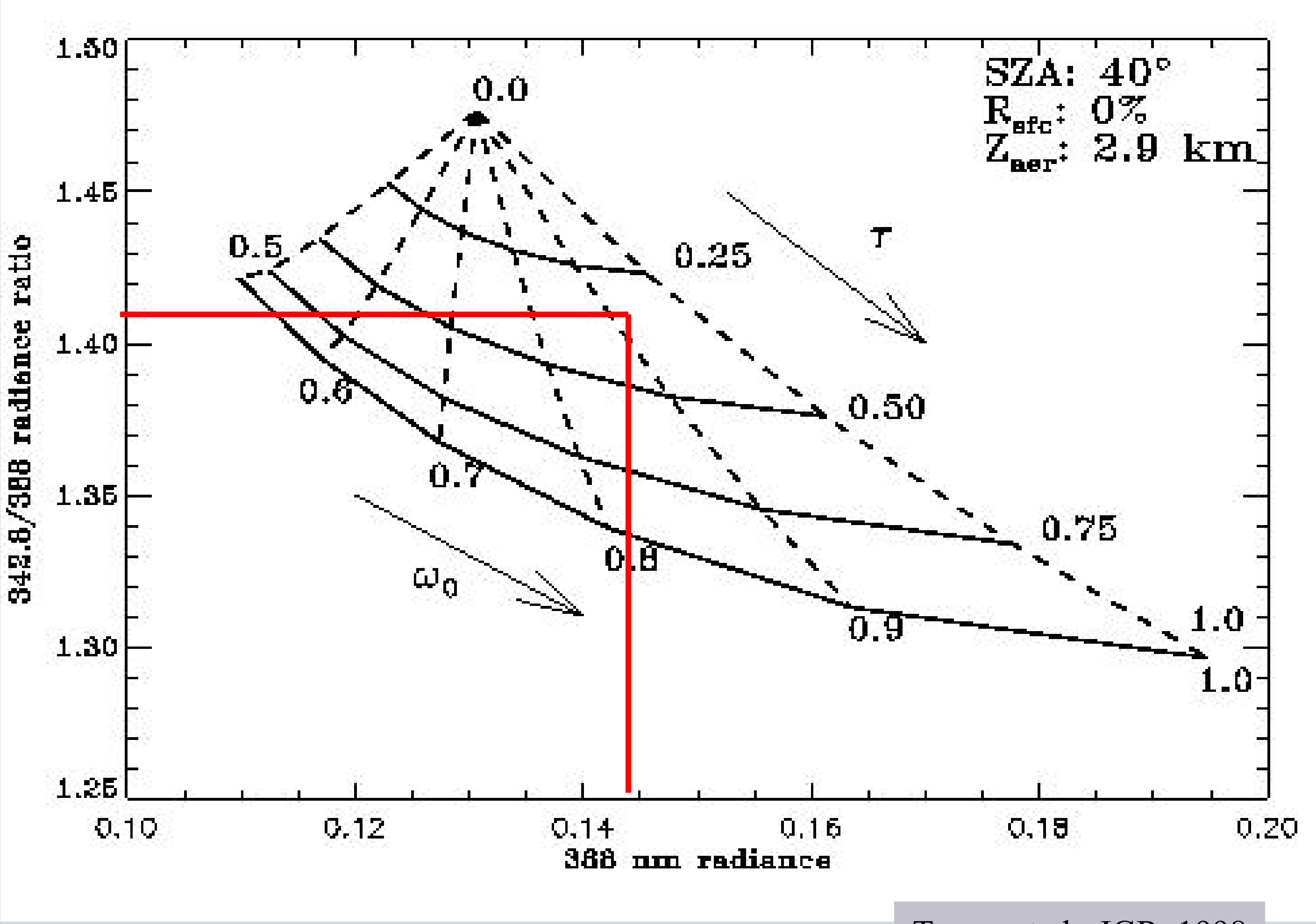
What can we do from satellites? SSA

- **Aerosol Index, related to the product of AOD and SSA (TOMS)**



What can we do from satellites? SSA

OMI near UV retrieval scheme



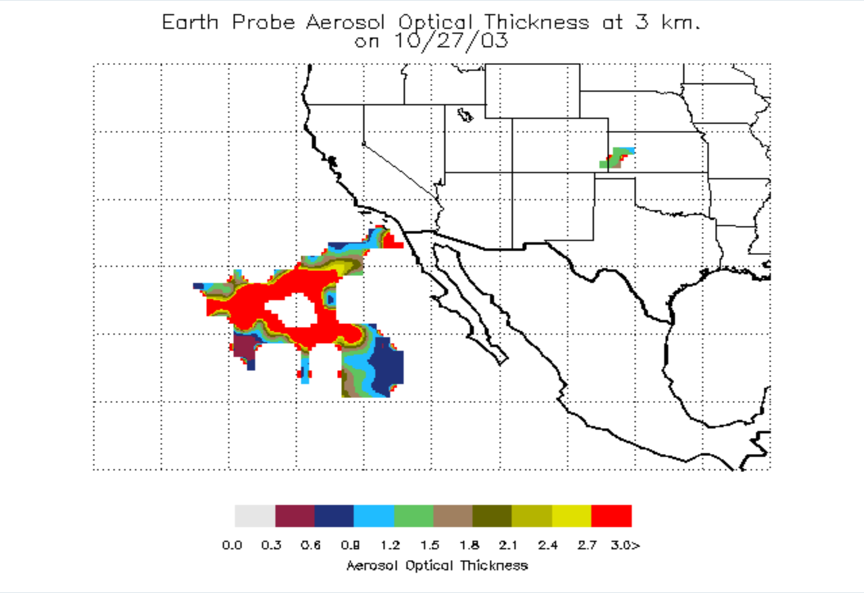
Torres et al., JGR, 1998

What can we do from satellites? SSA

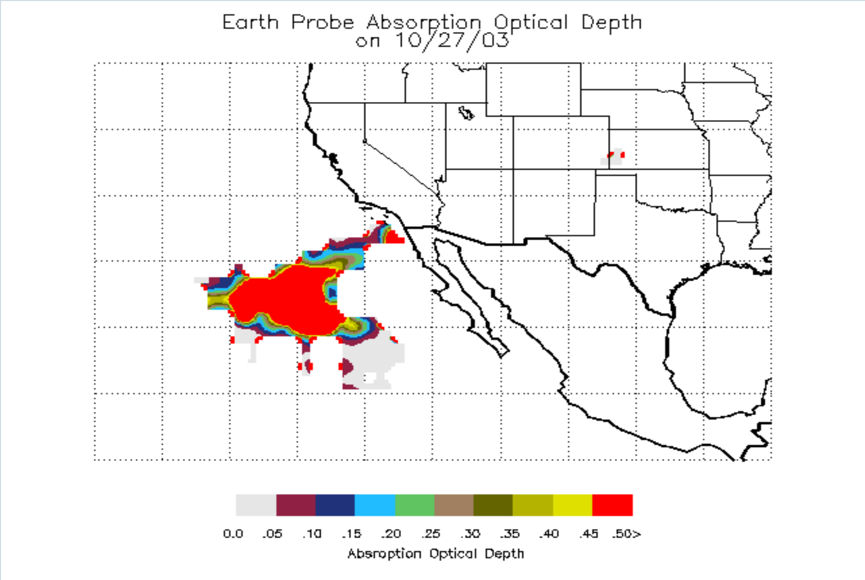
- **Measure the smoke or pollution ability to absorb sunlight (TOMS)**

--> indicates BC presence

Aerosol Absorption from TOMS observations



Extinction optical depth



Absorption optical depth

California Fires October 27-2003

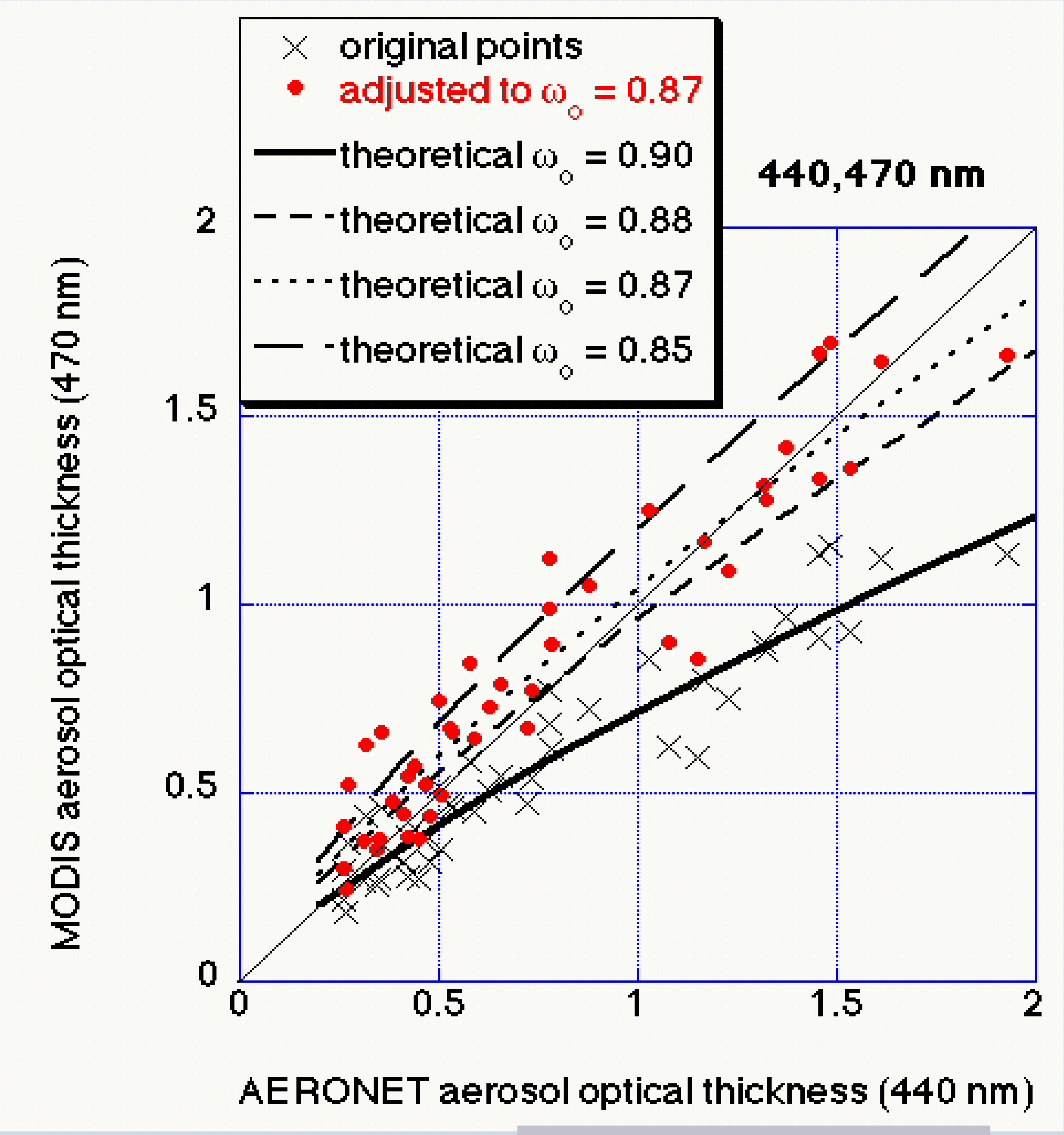
O. Torres UMBC/GSFC

Aerosol Absorption (SSA) from MODIS + AERONET

Finding the single scattering albedo (ω_o), the ratio of scattering to extinction - a measure of aerosol absorption

The measurements are adjusted from original (x) to values (•) on the diagonal by reducing SSA to ~ 0.87

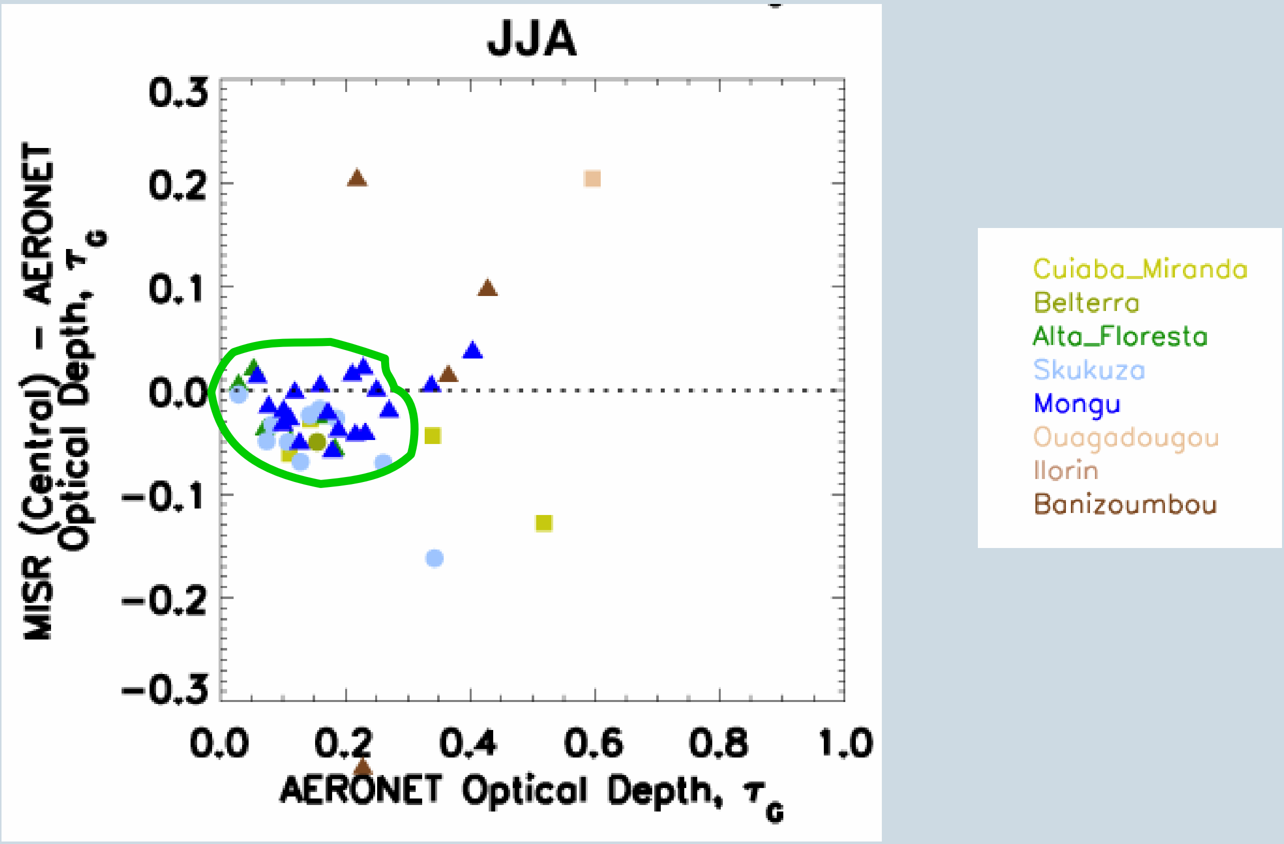
Savanna fires in Africa



C. Ichoku SSAI/GSFC

MISR-AERONET Coincident AOD Difference Plot

Biomass Burning Sites; 2001-2002; Summer Seasons



Retrieved AOD **skewed** 0.025 - 0.05 **too low** during burning season -->
Biomass Burning particles have **lower SSA** than original retrieval allowed

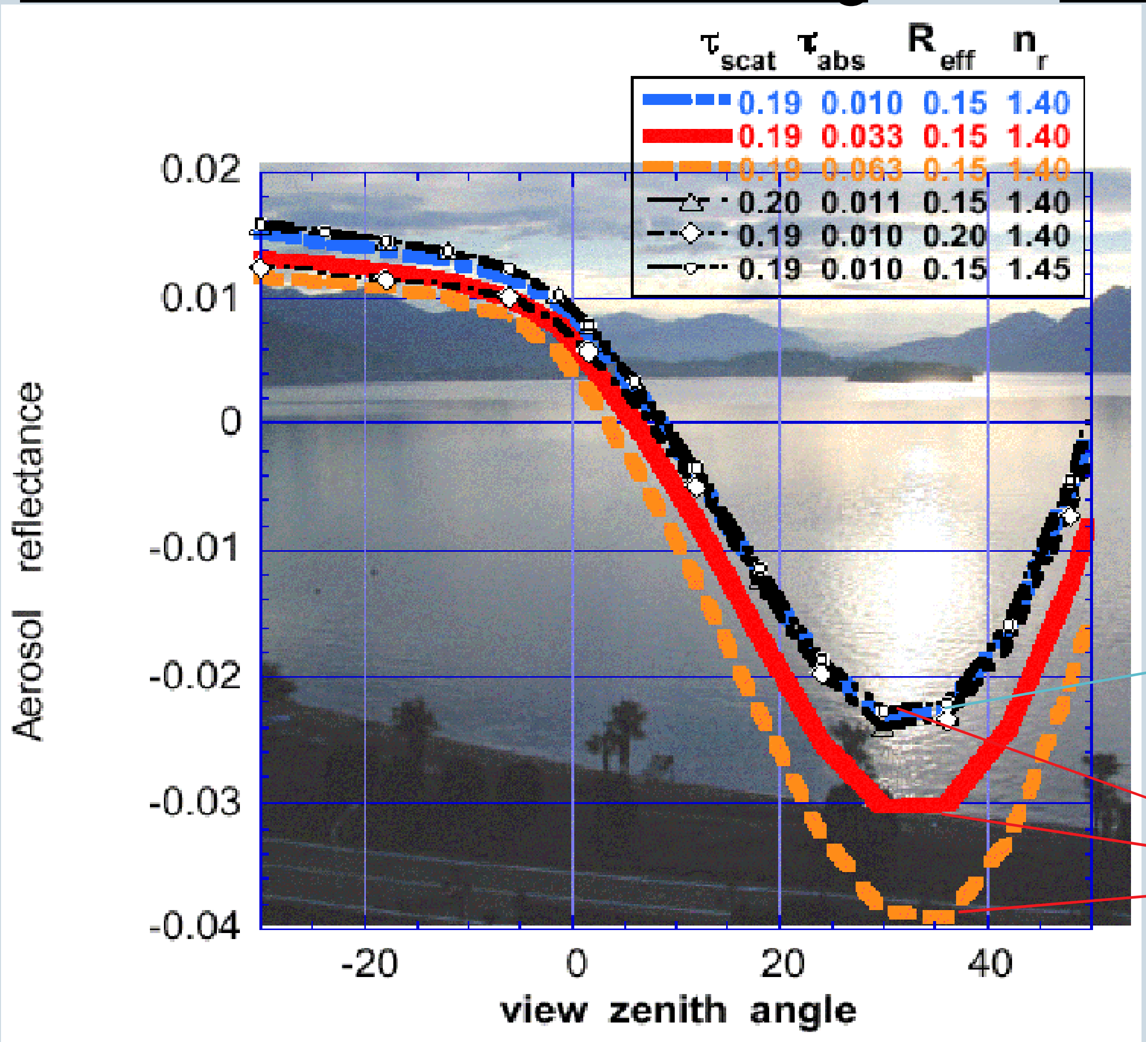
[MISR alone can distinguish SSA of 1.0 from ~0.9 from ~0.8 over dark water]

From: Kahn, et al., 2004, JGR (in press)

Aerosol absorption using sun-glint measurements

Over dark ocean satellite data are sensitive to aerosol scattering

Over the bright glint to Scattering+absorption



Aerosol effect on sun-glint reflectance is weakly dependent on aerosol effective radius and refractive index but strongly dependent on the absorption and scattering optical thickness

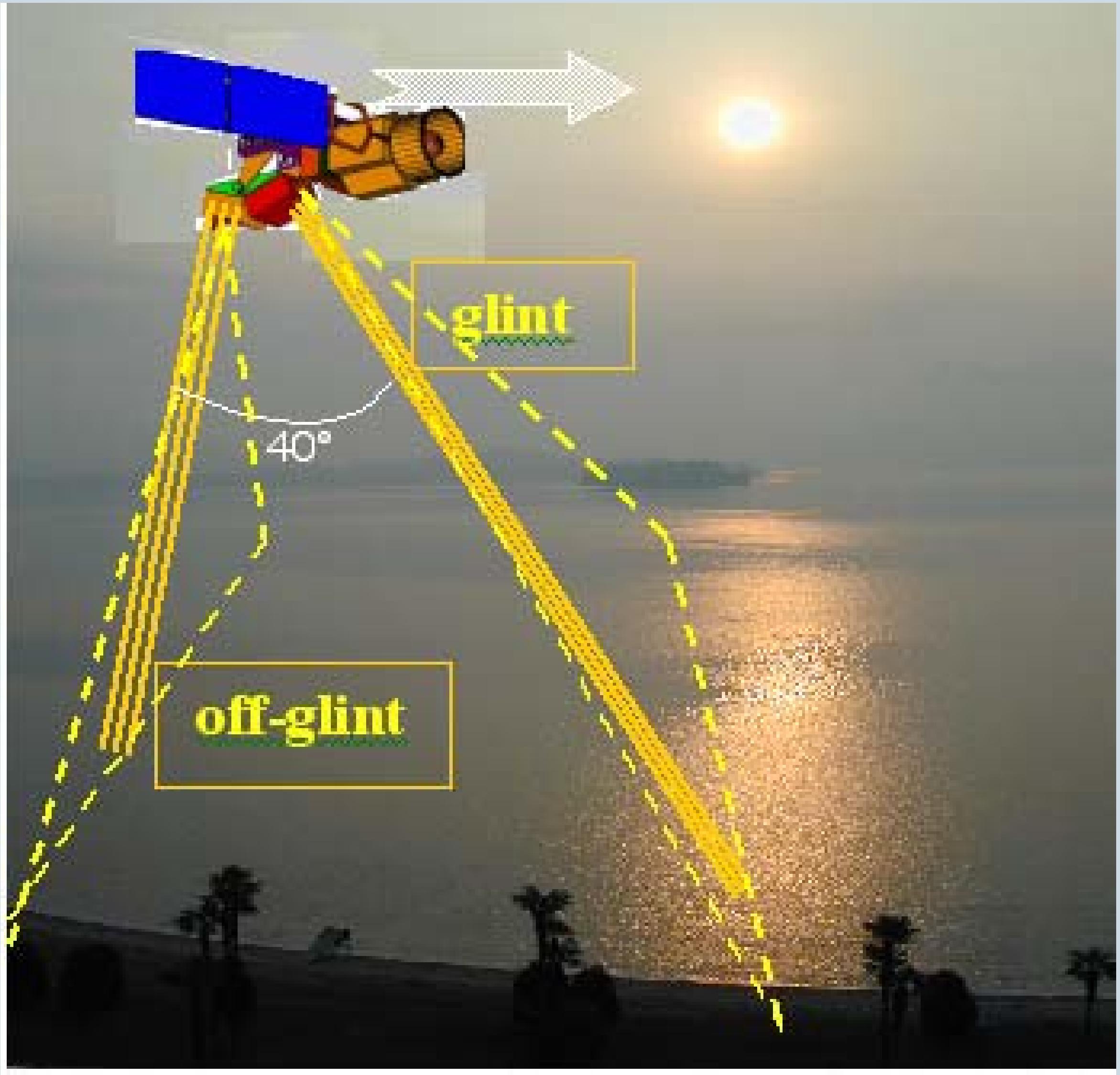
Varying effective radius and refractive index

Varying Absorption Optical Thickness

Kaufman et al., GRL 2002

How can we measure aerosol absorption over the glint?

Combination of simultaneous measurements at glint angle and off glint across the solar spectrum (0.4-2.2 μm)



Next Step:
How accurately
can SSA be retrieved?

What can we do with satellite data and models?

• Use **Inverse Aerosol Transport Model** initialized with **Satellite Aerosol Field** to constrain **Location**, **Strength**, and **Time** dependence of aerosol sources

Aerosol transport model

sources $\xrightarrow[\text{transformation}]{\text{Transport}}$ Global distribution

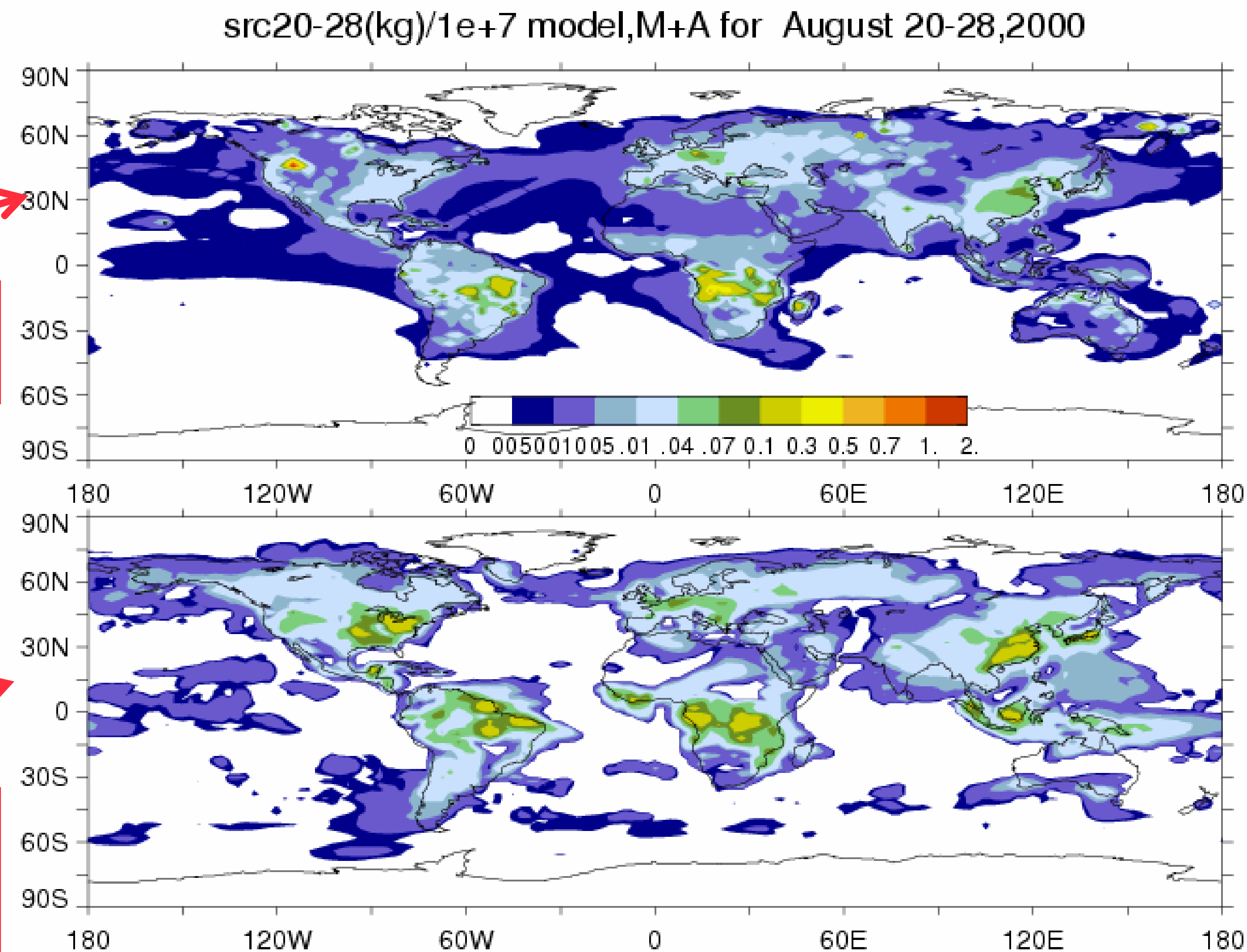
Global inversion model

Global distribution $\xrightarrow[\text{transformation module}]{\text{Transport}}$ sources

From: Oleg Dubovik

9 day average retrieval

Emission Sources

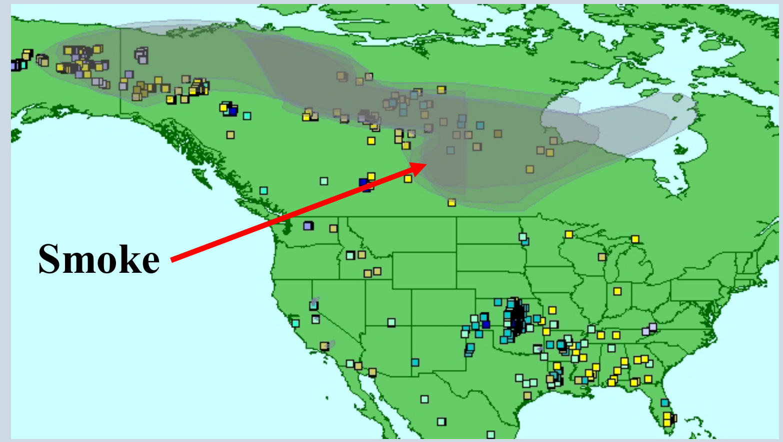


GOCART Emission: Sulfates + BC +OC

Retrieved Emission from MODIS+AERONET

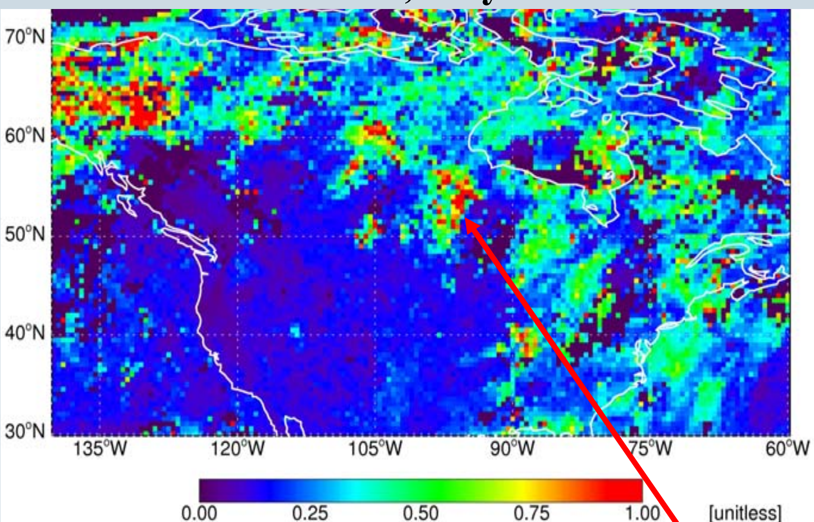
Alaskan Forest Fire Plumes During ICARTT

HMS Fire and Smoke, July 15, 2004

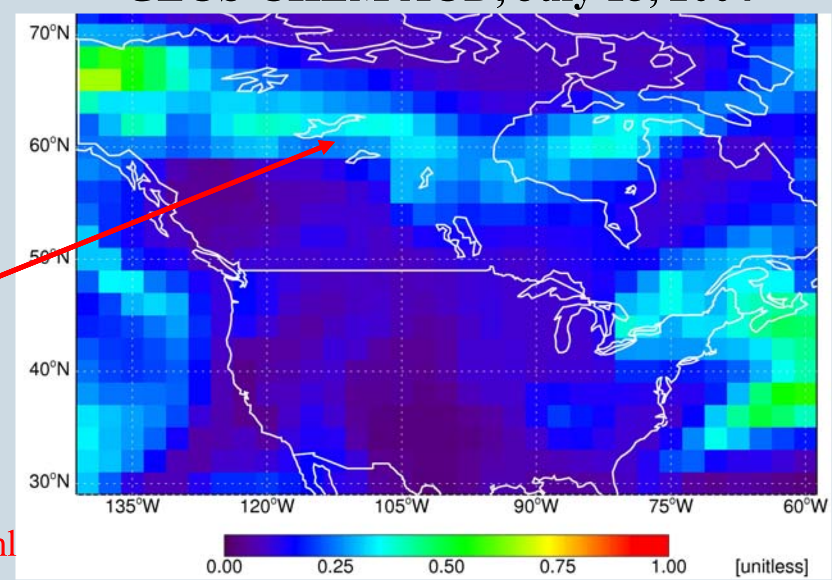


NOAA Hazard Mapping System Fire and Smoke Product:
http://www.ssd.noaa.gov/PS/FIRE/hms.html.

MISR AOD, July 2004



GEOS-CHEM AOD, July 15, 2004



Smoke aerosol AOD

GEOS-CHEM is a global 3-D model of tropospheric chemistry-aerosols driven by assimilated meteorology.
http://www-as.harvard.edu/chemistry/trop/geos/index.html

Qinbin Li et al., 2004 in preparation

Conclusions

Satellite Instruments Can Contribute:

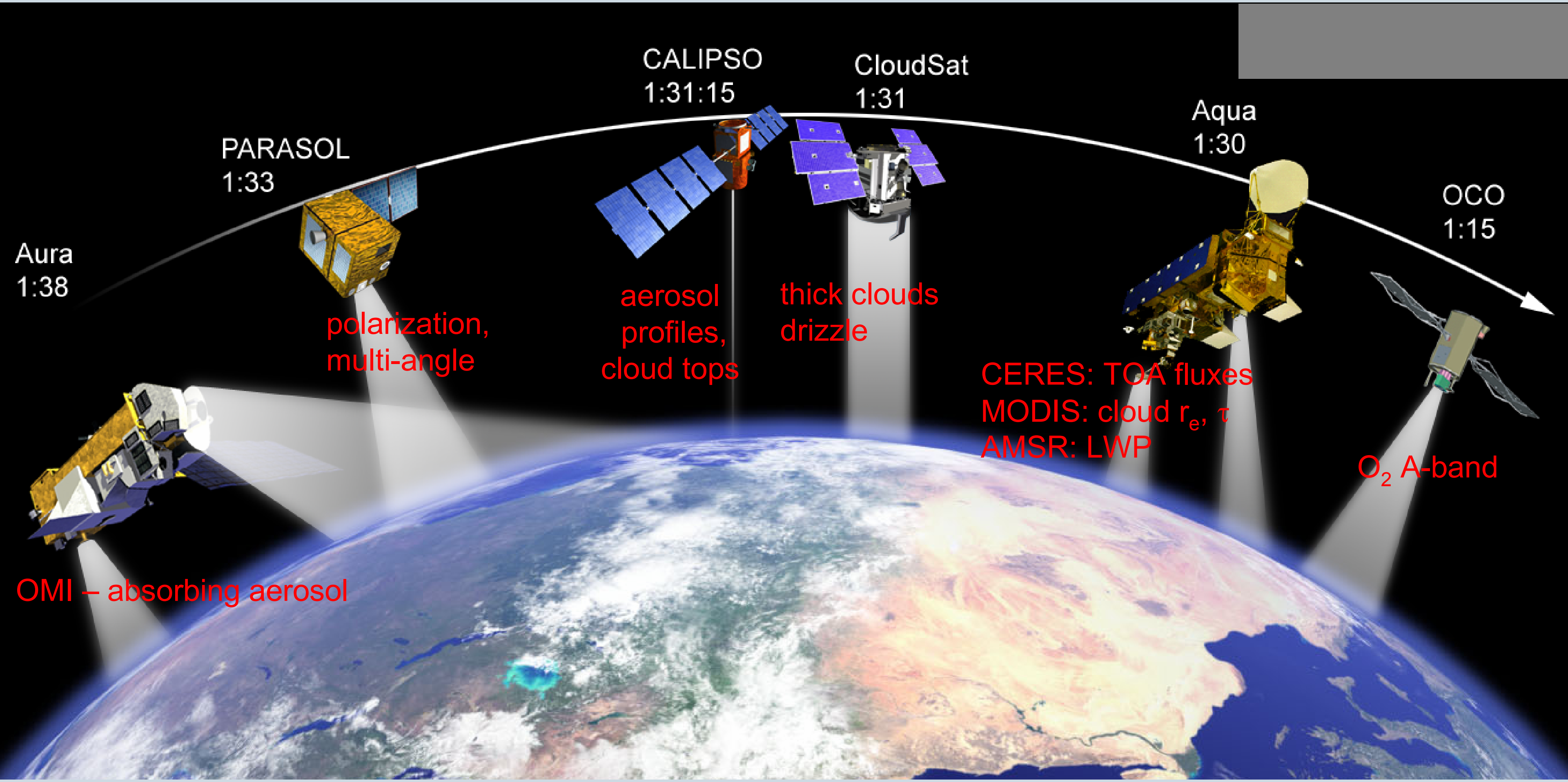
- Frequent, ***Global*** **Coverage**
- Aerosol **Amount** and Type over Land and Water
- Aerosol **Vertical Distribution**
- **Plume Height**, especially near Aerosol Source Regions
- Constraints on **Single-Scattering Albedo**
- Constraints on Aerosol **Source Location**, **Strength**, and **Timing**

→ Black Carbon **amount**, to the accuracy required to constrain SSA to a few %, aerosol **mixing state**, and **vertical distribution stratified by aerosol type**, must be derived or inferred from other sources.

→ The **COMBINATION** of **Satellite**, **In Situ**, and **Surface** Observations, along with Transport **Modeling**, is required to produce both the extensive **Coverage** *and* sufficient **Detail** needed to assess the Black Carbon Aerosol impact on global climate.

The "A-Train"

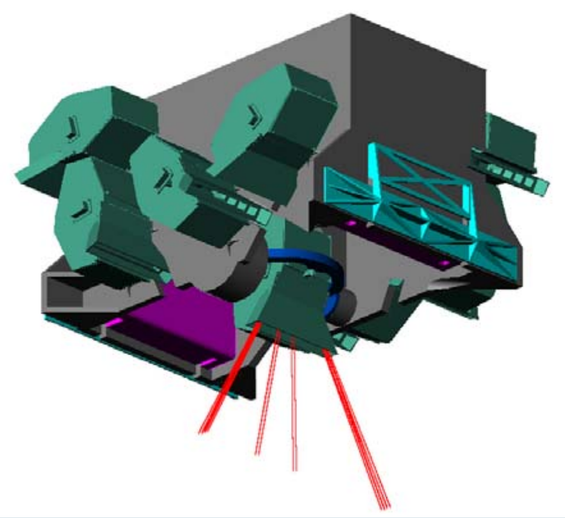
Moving Toward the Future of Integrated Earth Observation



Unified LEO/MEO Advanced Aerosol Instrument concept

Multiangle spectropolarimetric imager combining key attributes of many aerosol sensors (MISR, MODIS, AATSR, POLDER, TOMS/OMI, APS) into a single instrument

Spatial resolution	Along-track angle range	Spectral range	Polarization accuracy	Multiangle global coverage
250 m - 1 km	70º fore - 70º aft	380 - 2130 nm	0.5%	3 - 4 days



Approach	Strength
Multispectral	Particle size (visible and SWIR), absorption and height (near-UV)
Multiangle	Particle size, shape, retrievals over bright source regions, plume-top altitudes
Polarization	Size distribution, refractive index
Imaging	Cloud discrimination, global coverage, stereoscopy

Diner et al., AIAA, 2004

A hyperspectral Imager at the L-1 vantage point combines the full global coverage of a LEO mission with the time-dependent observations of GEO.

Observing Mission to L-1

Hyperspectral Imagers: 310 nm to 905 nm, and 1 to 2 microns.
High Signal to Noise (1000:1)
Large Dynamic Range
Spatial: 2 to 4 km
Temporal: 60 minutes
Coverage: Full Day-Side Disk

Time Evolution of Atmospheric Processes from Sunrise to Sunset for the Entire Earth

Measure some or all of:

O_3, SO_2, H_2O, NO_2, CH_4, CO, CO_2, Aerosols (dust, smoke, and sulfate pollution),

Cloud height, Cloud reflectivity,
Cloud phase, Cloud optical depth,
UV radiation, Vegetation index,
Ocean color, Weather systems

Key Question…

What must each component:

- **Satellites**
- **In Situ** & **Surface** Observations
- Transport **Models**

bring to the table, and how must these inputs be combined, to produce a sufficiently accurate and complete global aerosol absorption picture to understand Aerosol Absorption Climate Impact?

Ref. -- The "PARAGON" papers, BAMS, October 2004